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Precision Runway Monitor Demonstration Report

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16. Abstract

This report is prepared as the result of a development and demonstration project to increase landing capacity on closely spaced parallel runways. The project developed new equipment and procedures, and demonstrated them in a variety of ways at two different airports.

The new monitoring equipment consists of radars and displays. The system installed at Raleigh, N.C. included an electronically scanned antenna capable of half-second update intervals, while the Memphis, TN installation provided a mechanically rotating "back-to-back" antenna with a 2.4-second update interval. In addition, both sites provided enhanced high-resolution color ATC display systems.

The purpose of the report is to present findings relevant to a decision concerning whether or not the current standard for runway separation of 4,300 ft can be reduced to 3,400 ft when the precision runway monitor equipment is utilized. The 3,400-ft separation was the spacing demonstrated most often in both simulations and flight tests. The demonstration produced a broad recognition that both system could be used to monitor parallel runways spaced at 3400 foot apart. 25 * Instrument landings

The report recommends accuracy, update rate, and display requirements for the PRM radar. It does not recommend specific equipment or acquisition strategies, although it takes note of further development planned for the equipment used during the demonstrations.

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Foreword

This report is prepared as the result of a development and demonstration project to increase landing capacity on closely spaced parallel runways. The project developed new equipment and procedures, and demonstrated them in a variety of ways at two different airports.

The purpose of the report is to present findings relevant to a decision concerning whether or not the current standard for runway separation of 4,300 ft can be reduced to 3,400 ft when the precision runway monitor equipment is utilized. The 3,400-ft separation was the spacing demonstrated most often in both simulations and flight tests.

There is a considerable amount of additional data from the project which have not been fully analyzed at this time. Further analysis, combined with new data, will undoubtedly be useful in considering changes based on other combinations of runway separation, equipment, and procedures. While some of the additional data are included in this report, conclusions based on these data will be deferred until additional analysis can be completed. These additional data will have no impact on the specific recommendations presented in this report.

Much of the data in the report is presented at the summary level. Report deadlines prevented, in some cases, inclusion of the last few weeks of demonstration data. The data were sufficient, however, to support the recommendations of the report. More detail and the complete set of data will be available in specific reports prepared by two demonstration contractors and the FAA Aeronautical and Technical Centers.

The report recommends accuracy, update rate, and display requirements for the PRM radar. It does not recommend specific equipment or acquisition strategies, although it takes note of further development planned for the equipment that was used in the demonstration.

Executive Summary and Recommendation

This report documents the results of the precision runway monitor (PRM) equipment development and demonstrations of that equipment at the Memphis, TN, and Raleigh-Durham, NC airports. The report recommends a new standard for the minimum allowable runway separation for simultaneous independent approaches to parallel runways.

Background

The primary purpose of radar monitoring is to insure safe separation of aircraft on the parallel approach courses. This separation is compromised if an aircraft blunders off course towards an aircraft on the adjacent approach. The PRM allows controllers to direct either aircraft to avoid a collision. Resolution of a blunder is a sequence of events: the monitor displays the blunder, the controllers intervene, and the pilots comply with controller instructions.

This process was modeled by the MITRE Corporation in 1975, and calibrated to the current minimum spacing of 4,300 feet when monitored by an ASR-4 radar and Automated Radar Terminal System (ARTS) displays. A 1981 MITRE study subsequently extended the analysis to consider surveillance improvements and predict that a system with a 1-second update interval and 1-milliradian (0.06 degrees) azimuth accuracy could monitor approaches to runways spaced as closely as 3,000 feet.

Using the predictions of the model as a guide, in 1987 the Federal Aviation Administration (FAA) began to build two radar systems to demonstrate the potential for monitoring at reduced spacing. By 1989, engineering models of two radar and display systems had been set up, one at Raleigh and another at Memphis, to demonstrate the new capability and to collect data on blunder resolution performance.

The new monitoring equipment consists of radars and displays. The display portions of both systems were functionally equivalent, but the radars were not. An electronically scanned antenna capable of half-second update intervals distinguished the system installed at Raleigh, while a mechanically rotating "back-to-back" antenna with a 2.4-second update interval was installed at Memphis.

Determination of the update requirement was a major objective of the demonstration. To achieve this, a variety of simulations allowed controllers using PRM displays to resolve blunders of computer generated targets and targets representing the positions of both flight simulators and live aircraft. The participating controllers came either locally from Memphis or Raleigh, or visited from airports which conduct independent parallel approaches. Pilots were qualified in transport aircraft: most came from scheduled airlines.

Before the demonstration began, it was agreed that a successful demonstration must satisfy three criteria: (1) participating pilots and controllers must judge the system safe, (2) no less than a 500-foot separation between aircraft must be achieved during a variety of blunder scenarios, and (3) a risk model must show that the overall risk of closely spaced parallel approaches was very low.

Overall Results

The demonstration produced a broad recognition that the systems could be used at the 3,400-foot spacing at which they were tested. It achieved the 500-foot miss distances in the practical demonstrations. It also collected a considerable amount of data on the

elements of the blunder resolution process which, when incorporated in a risk model, predicts a satisfactorily low risk. The following paragraphs summarize how well the system met the criteria.

Criterion 1 - Participant Judgment

The judgment of controllers was obtained when participants completed surveys and volunteered their opinions. Controllers liked the equipment, and believed it could be used to reduce the standard runway spacing to the 3,400-foot spacing demonstrated. All of the controllers viewed 2.4-second update interval, and a faster update interval of either 1.0 or 0.5 seconds. Ninety-five out of 100 controllers agreed that approaches could be safely conducted at the 3,400-foot spacing if monitored by the PRM. The remaining five controllers would have liked more time with the system before making a decision.

Pilot evaluations were obtained from pilots who participated in flight simulators and from others who flew FAA aircraft. Eighty-two percent of the pilots agreed that independent approaches with reduced runway separations could be conducted safely with the PRM. Three percent of the pilots disagreed and fifteen percent were undecided. Pilots who were undecided were mostly those at the remotely located flight simulators who did not have an opportunity to see the PRM display or to observe the position of their own aircraft relative to the computer simulated blundering aircraft.

Several pilots were concerned with the turn onto the localizer. Others were concerned about the interaction of the Traffic Alert and Collision Avoidance System (TCAS) with PRM. Some pilots commented that the blunder resolution maneuver, an immediate turn away from the approach course near the runway threshold, was a maneuver to which they were not accustomed. A few pilots were concerned that the communications frequency used to transmit the blunder instruction would be blocked by another aircraft. Each of their concerns has been addressed.

Criterion 2 - 500-foot Separation

Separation at closest point of approach for flight simulator and live aircraft blunders was greater than 500 feet in all cases except for a few flight simulator runs. Those less than 500 feet were due to equipment problems, communication problems or very slow pilot responses. Problems uncovered by these runs have been examined in detail and resolved. When safety considerations prompted the blundering aircraft to break off the maneuver during live aircraft tests, the miss distances were computed analytically by extending the track as though the blundering aircraft had not recovered.

Criterion 3 - Risk Model

The 1981 MITRE model combines the "worst case" values for several blunder resolution elements (eg.,blunder angle, lateral distance of evader from centerline) and nominal values for other parameters to determine how far a blundenng aircraft could travel before the endangered aircraft could be turned away. The model then used that distance to determine a minimum runway spacing. The MITRE work used a long agreed-to "worst case" blunder where an aircraft turns 30 degrees off the approach course and ignores controller instructions to return.

This study uses a new model developed by Lincoln Laboratory which provides the risk of not achieving a miss distance of at least 500 feet. It works by simulating 100,000 blunders, with values for each the relevant variables (radar update interval, display predictor lead time, controller and pilot response times, time to obtain a clear

communications channel, and initial spacing of the aircraft) randomly selected from those measured during the demonstration. For each of the 100,000 cases, a miss distance is computed, and from all cases, a percentage is tallied of those which are less than 500 feet. (A miss distance of less than 500 ft does not necessarily result in a mid-air collision; but the number has been used as a threshold in other studies to suggest an unacceptably close encounter.)

The model is a useful tool for evaluating the effect on risk of changes in the relevant variables. The table which follows shows some of the results for a 3,400-foot runway separation. Of interest in these numbers is the relatively small effect of shorter update interval and the strong dependence on blunder angle. The choice of the worst case blunder angle of 30 degrees strongly affects the risk, and thereby the runway spacing. Other significant factors are the ranges of controller and endangered pilot response times. The risks are radically reduced if the unusually long pilot responses from the demonstration are eliminated, suggesting that pilot training could greatly decrease the odds of a near miss.

Blunder Resolution Failure Probabilities
Conditions: IMC, Blundering Aircraft Does Not Recover

Unresolved Blunders	Update (s)	Blunder Angle (deg)	Blunder Range (nmi)
1 in 257	2.4	30	10
1 in 313	1.0	30	10
1 in 254	2.4	30	2
1 in 25,000	2.4	15	10

The risk added to a particular approach by the introduction of simultaneous parallel approaches at more closely spaced runways can be determined from the numbers in the table if the rate of blunders is known. Yet, no blunder -- worst case or other -- has ever resulted in an accident, and there is only anecdotal evidence of blunders without accidents. A sustained 30 degree blunder would be a memorable event for a monitor controller or pilot. But today, with parallel approaches conducted at several busy airports (with runways separated by 4,300 feet or more), few pilots or controllers have ever witnessed or even heard of such a blunder.

One way to evaluate closely spaced parallel approach safety without blunder data is to select an acceptably small "per approach" accident rate, and then compute a rate of blunders that, combined with the PRM's ability to resolve them, attains that level. If that rate is well above anyone's intuitive sense of how often blunders occur, then the system will be well above the desired level of safety.

National Transportation Safety Board (NTSB) accident data from 1983 through 1988 show that two fatal accidents occurred during precision approaches in instrument meteorological conditions in the United States, yielding a rate of 1 per 2.5 million approaches. If one assumes that the introduction of closely spaced parallel approaches should add a risk of not more than one tenth of that level, then a risk level of 1 per 25 million approaches must be achieved.

One way to see if the required accident rate can be achieved is to compute how frequently blunders can occur and still satisfy the criterion. The maximum blunder rate that satisfies the criterion is about one in 2,000 approaches: if blunders were occurring at that rate or less, the desired level of safety would be achieved. At that rate, Chicago would

have to report ten 30-deg blunders per year during instrument meteorological conditions (IMC), Atlanta would report 14 per year. Anecdotal evidence suggests that the actual number of 30-deg blunders at these airports is no more than one per year. This suggests that the actual accident rate due to midairs during PRM operation will be on the order of 1 per 250 million approaches. At that rate, with PRM deployed at about 10 airports, an accident related to a blunder on a closely-spaced parallel runway could be expected, on average, about once per 2,000 years.

Additional Study Results

Equipment: Each piece of equipment tested was an "engineering model," meaning that it was not easily maintainable, had no designs for necessary reliability, and therefore could not be used in operational service. Extensive field tests demonstrated that the equipment did, however, meet all of the technical performance specifications which would exist in a production system. The demonstration showed that these performance specifications were sufficient to reduce the runway spacing to 3,400 feet. Some tests will need to be repeated on production versions of the equipment to make sure that it maintains the performance specifications of the model.

Pilots: Several studies to characterize the response of the endangered aircrew and aircraft to an air traffic control (ATC) instruction to turn were conducted utilizing both live aircraft and full-motion flight simulators. Three aircraft types were studied: Boeing 727 (live, simulator), McDonnell Douglas MD80 (simulator), and McDonnell Douglas DC10 (simulator). In the live aircraft study, the average time between the start of the controller instruction to turn and the start of the B727 turn was about 5 seconds. All response times were less than 15 seconds. In the B727 flight simulator studies, the average response time was 7.3 seconds when the aircraft was at a 100-foot decision height and 4.5 seconds when the aircraft was six nautical miles from the runway threshold.

Some of the pilots required more than 15 seconds to initiate the turn in the flight simulators. Two factors contributing to the slow responses were: pilots did not understand the need to respond quickly and chose to fly the published missed approach; and pilots had difficulty disengaging the MD80 autoland mode and returning the aircraft to manual control. These experiences led to the requirement for additional training before closely spaced parallel approaches would be allowed.

Controllers: One measure of controller response is net lead time, defined as the time from when the controller begins to break out the endangered aircraft to when the blundering aircraft penetrates the no transgression zone (NTZ). Net Lead Time is affected by changes in the time, relative to NTZ penetration, when display alert sounds. The net lead time provided by the 1-second update interval was about one second greater than the lead time provided by the 2.4-second interval, and three to four seconds greater than the 4.8-second interval.

Alert response time was also analyzed. This is defined as the time interval from the caution alert to the controllers' breakout response. The alert response times did not vary significantly with update interval so that the net lead time differences are mainly due to the effect of sensor update interval on the generation of caution alerts. This suggests that the controllers took advantage of the predictive alert in responding to a blunder.

The effect of the blunder deviation angle on the alert response time of controllers was also studied. When the simulation was presented at 0.5-, 1.0-, and 2.4-second update intervals, with runway separation of 3,400/3,500 feet, the angle of the approach blunder deviation was found to significantly affect the alert response time of the controllers

Controllers reacted one second sooner to the 30-degree blunder deviations than to the 15-degree deviations.

Measurements of the rate of unnecessary breakouts are heavily dependent on the specific test scenario. Scenarios involving abrupt deviations (which recover in time to avoid an NTZ penetration) created a higher percentage of unnecessary breakouts than did scenarios involving normal flight technical errors. In all cases, the faster update intervals outperformed the slower intervals in avoiding unnecessary breakouts. The rate of unnecessary breakouts was not significant in either scenario type.

Recommendation

It is recommended that the FAA issue a national standard for runway spacing of 3,400 feet, provided the approaches can be monitored by displays equivalent to those used in the demonstration, driven by a radar accurate to within 1 milliradian with an update interval of 2.4 seconds or less. With this equipment, the risk of a blunder resulting in less than 500 feet of separation when two aircraft are on parallel approach in IFR conditions, is less than one in 250 million instrument approaches. This recommendation is contingent on successful deployment of a satisfactory surveillance and display system. A familiarization program to ensure that all pilots understand their responsibilities during a closely spaced parallel approach will also be required. An off-centerline obstruction evaluation will be conducted at all airports where the PRM is to be installed.

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1. INTRODUCTION

One of the major aviation problems of recent years has been the steady increase in the number and duration of flight delays. Airports have not been able to expand to keep pace with traffic growth. The Federal Aviation Administration (FAA) has taken a variety of measures to increase airport capacity. These include revisions to air traffic control procedures, addition of landing systems, taxiways, and runways, and application of new technology. The Precision Runway Monitor (PRM) program is one of these new initiatives. PRM is an advanced radar monitoring system intended to increase utilization of multiple, closely spaced, parallel runways in bad weather.

FAA designed two versions of the new radar, and a new display system for the air traffic controller. It then installed prototypes of the systems at two airports, one in Memphis, TN and the other in Raleigh, NC. The systems were operated in a test and demonstration that brought together equipment, procedures, controllers, pilots, and aircraft to evaluate the safety and effectiveness of the new system. This document is a report of that evaluation.

1.1 Background

1.1.1 Simultaneous Instrument Landing System Procedure

This section describes how pilots navigate and how controllers direct them to land in bad weather. These techniques are first described for a single runway, and then for multiple runways at the same airport. Next, existing limitations to full runway utilization are explained, followed by a discussion of how the limitations might be avoided with PRM.

1.1.1.1 Instrument-Approach Procedures

During instrument meteorological conditions (IMC), a variety of procedures have been developed to guide appropriately equipped aircraft safely to the vicinity of the runway. The most precise procedure in common use is the Instrument Landing System (ILS). Radio-navigation signals identify a precise flight path, laterally with the localizer, and vertically with the glideslope. The signals are displayed to the flight crew on an instrument that indicates the location of the flight path relative to current aircraft position.

At busy airports, air traffic controllers use radar to direct the aircraft to intercept the localizer five to fifteen nautical miles (nmi) from the runway threshold. Aircraft reach this intercept one at a time, separated by at least three nautical miles from the aircraft ahead. The aircraft then follow the localizer signal at constant altitude, and begin descending when the glideslope is intercepted. When an aircraft reaches the missed approach point (MAP), typically 0.5 nmi from and 200 ft above the runway threshold, the flight crew must be able to see the runway environment and complete the landing visually. If they are unable to do so, they must reject the landing and follow a missed approach procedure.

1.1.1.2 Parallel Runway Simultaneous ILS Approaches

The procedures for airports with multiple parallel runways are similar, with added safeguards to ensure that an aircraft approaching one runway is safely separated from those approaching the adjacent parallel runway. The procedures are discussed in [1], and an example of such procedures is diagrammed in Figure 1-1. Aircraft are directed to the two final approach courses at altitudes which are different by at least 1,000 ft. The separation is necessary because the normally maintained 3-nautical mile separation is lost as the aircraft

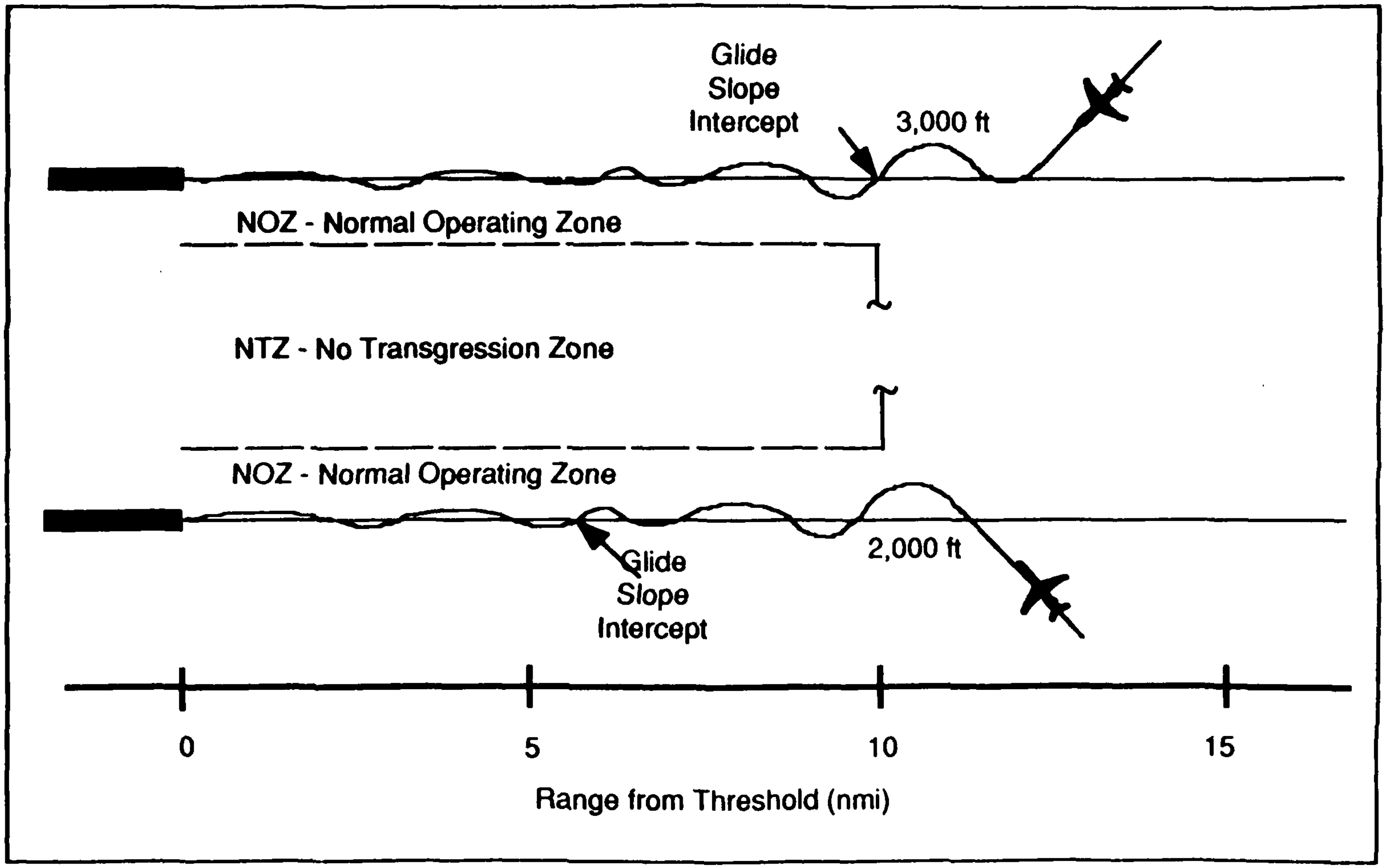

Figure 1-1. Parallel runway approach zones.

fly toward their respective localizers. This 1,000-ft vertical separation is maintained until the controller sees that each aircraft is stabilized on its parallel localizer course. Then, the aircraft are allowed to descend on the glideslope, flying towards the airport separated by the distance between the runway centerlines.

Because this separation is much less than the three nautical miles normally maintained, the two aircraft are monitored on radar starting when the 1,000-ft altitude buffer is lost as the higher aircraft starts down the glideslope. Two controllers observe the parallel approaches and ensure that if an aircraft blunders from the normal operating zone (NOZ) into a 2,000-ft no transgression zone (NTZ), as shown in Figure 1-1, any endangered aircraft on the other approach are turned away in time to prevent a collision. This maneuver on the part of the endangered aircraft is termed a "breakout," because the aircraft is directed out of the approach stream to avoid the blundering aircraft. Two controllers are necessary so that one can attempt to turn the blundering aircraft back to its localizer while the other directs the breakout. Typically, two separate radio frequencies are used, one for each approach.

The 2,000-ft NTZ, flanked by two equal NOZs, is a procedural artifice which provides strong guidance to the monitor controller. Aircraft are allowed to operate on or near the approach course within the limits of the NOZ. If an aircraft strays into the NTZ, it is deemed to create a hazard for an aircraft on the adjacent course. The NTZ width allows time to resolve the situation by redirecting either or both aircraft before a collision occurs. The 2,000-ft NTZ width has an uncertain origin, but pilots and controllers are confident that it is appropriate, based on many years of application at the wider runway spacings.

The smaller the separation between the runway centerlines, the shorter the time that is available to correct a blunder once it begins. Parallel approaches to runways spaced less than 4,300 ft apart are restricted in instrument meteorological conditions (IMC), in part because the radar and display systems available to the controller are sufficiently imprecise that the blunder cannot be detected and corrected before the aircraft are dangerously close. For these narrower runway spacings, the procedures are modified to eliminate the risk. Controllers position aircraft so that there is always at least two nmi separating an aircraft from another on the adjacent runway. This ensures that if an aircraft blunders toward the adjacent approach, the aircraft will pass through a gap and will not encounter another aircraft. Figure 1-2 diagrams the two situations: simultaneous independent parallel approaches, when aircraft on one runway are spaced independently of those on the other runway (for runway spacings of 4,300 ft or greater); and dependent parallel approaches, when aircraft are spaced dependent on the position of aircraft on the adjacent runway (for spacings less than 4,300 ft). The possibility of wake turbulence restricts dependent parallel approaches to spacings of 2,500 ft or greater.

1.1.2 Arrival Rate Penalties for Dependent Approaches

For independent approaches to parallel runways, the arrival rate is about twice the single runway rate, since the approaches to each runway are independent and managed by different controllers. But the arrival rate at airports using dependent parallel approaches is significantly less. The required two-nautical mile diagonal separation leaves just under four nautical miles spacing, at minimum, between aircraft on the same runway. Independent approaches leave a 3- or 2.5-nautical mile minimum. The different spacings yield a landing rate that is about 33% higher for the independent case. In practice, however, the coordination required to produce exactly the two-nautical mile diagonal spacing is much more complex, particularly as aircraft typically arrive from many different directions at a variety of speeds. To insure that the minimum is never violated, most controllers end up

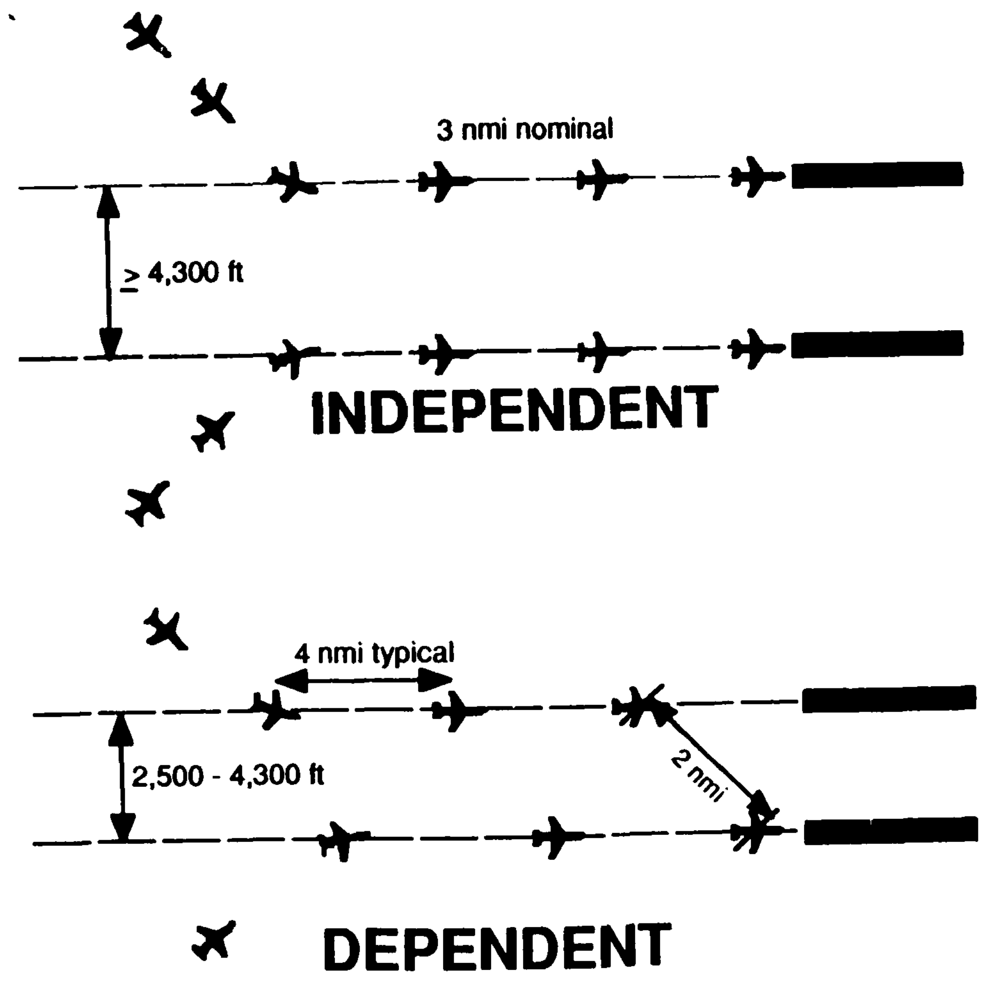

Figure 1-2. Independent and dependent parallel approaches.

with a spacing somewhat greater than the minimum, a reality which penalizes the dependent case even further.

Parallel runway acceptance rates are thus significantly greater when simultaneous independent approaches are available. Independence is possible at 700-ft runway spacings during visual meteorological conditions (VMC), but only at 4,300 ft or greater during instrument meteorological conditions (IMC). Numerous busy airports face arrival delays during IMC for this reason. Other airports with single runways are considering an additional parallel runway but are dissuaded from constructing it because land acquisition for a 4,300-ft separation is either impossible or extremely expensive.

This sets the stage for the PRM. If improved radar surveillance would lead to earlier blunder warning to the controller, independent approaches could be authorized at spacings less than 4,300 ft. Arrival capacity could be increased immediately at some airports, and construction at still other airports would yield greater benefits. Figure 1-3 shows parallel runway spacings at some busy airports.

1.1.3 Monitoring Options

The potential benefits from improved monitoring led to several studies that examined sensor options and evaluated them against aircraft, pilot, and controller performance. Data collected from several airports led to a reduction in minimum runway spacing for independent approaches from 5,000 ft in 1963 to 4,300 ft in 1974. A MITRE study in 1981 [2] examined the potential benefits of improved surveillance and concluded that the minimum runway spacing for independent parallel approaches could be further reduced. In particular, it indicated that a more accurate sensor, updating the controller's display at a faster rate, could lead to a minimum spacing in the 3,000-ft range. Table 1-1 shows results of the MITRE study regarding the effect of sensor update interval and root mean square (RMS) azimuth accuracy on minimum spacing.

Table 1-1

Minimum Runway Separation Summary*

RMS Azimuth Accuracy (mrad)	Update Interval (Seconds)			
	4	2	1	0.5
5	4,300	4,000	3,800	3,600
4	4,000	3,700	3,500	3,400
3	3,700	3,500	3,300	3,200
2	3,500	3,200	3,100	3,000
1	3,400	3,100	3,000	2,900

* Refer to [2] for values of other significant variables.

The accuracy and update rate requirements suggested by the MITRE study were reviewed in 1988 and it seemed likely that performance achievable from either of two surveillance sensors could meet those requirements for some or all of the candidate airports. The Mode S sensor, under production for deployment at over 100 U.S. airports, is specified to provide 1.2-milliradian azimuth accuracy (actual sensor accuracy has been measured to be better than 1 milliradian). The Mode S is designed for a single antenna installed atop the primary airport surveillance radar (ASR) which rotates at a

4.8-second rate. With a second antenna added at the back of the first, an update interval of 2.4 seconds could be achieved.

The alternative, an electronically scanned (E-Scan) phased array sensor developed by MSI Services, Inc. and the Bendix Corporation, would achieve 1-milliradian azimuth accuracy and provide a variable update interval with a minimum value as small as 0.5 seconds.

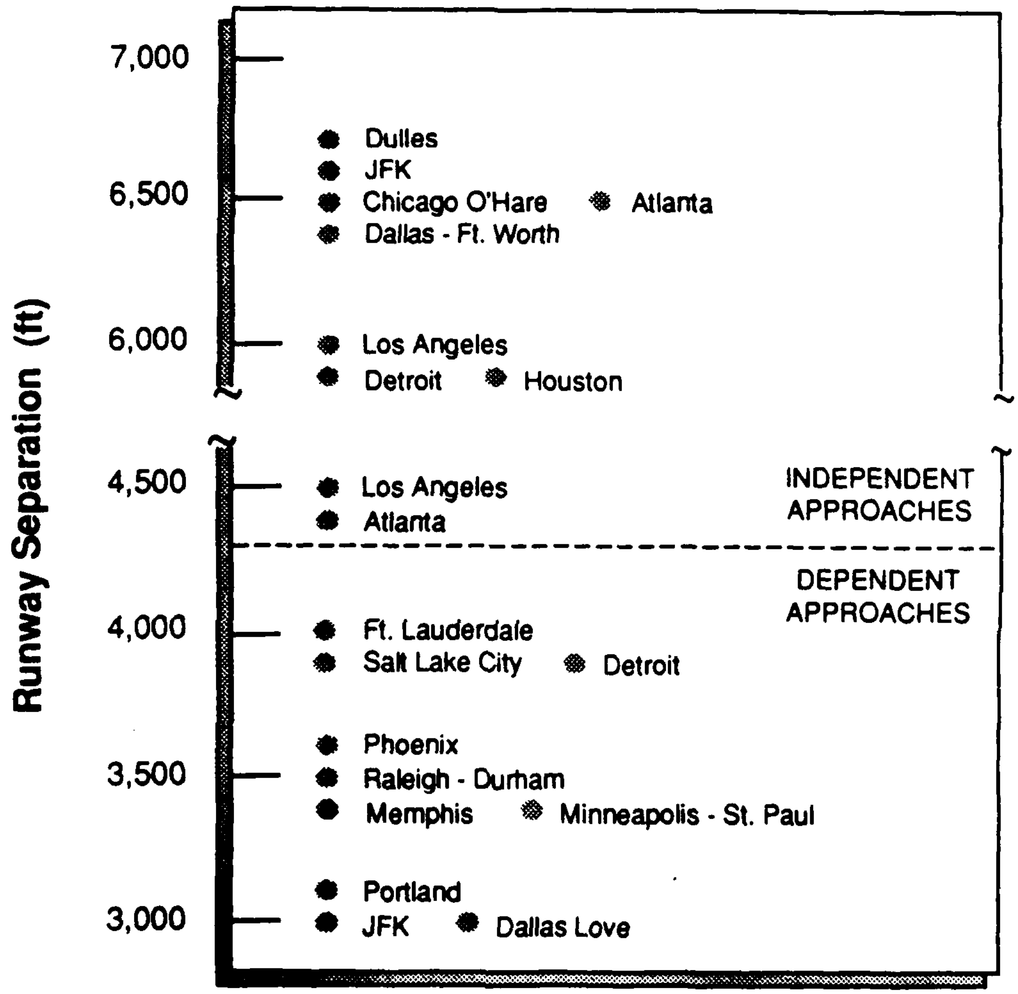

Figure 1-3. Parallel runway spacings. Airports with multiple runway pairings, such as Los Angeles, appear twice.

1.2 Objective and Approach

1.2.1 Objective

The principal objective of the Precision Runway Monitor Program is to develop an improved radar and the associated procedures necessary to lower the minimum required spacing between parallel runways for simultaneous independent ILS operations. This objective must be met with an equivalent level of safety and with minimal impact on current

air traffic and air crew procedures. The radar was to be designed, tested, and demonstrated in conditions approaching as closely as possible those in which it would eventually be used.

1.2.2 Approach

The program was motivated by the possibility, suggested by the theoretical studies, that better radar systems could make a difference in runway spacing. Equipment design and testing was therefore a major activity in the program. It was realized that the previous studies were based on limited data and on assumptions that would be altered by the new equipment. Furthermore, although these studies had focused on blunder resolution as the major safety issue in parallel approaches, it was recognized that ancillary issues, such as unnecessary breakouts, or use of the Traffic Alert and Collision Avoidance System (TCAS), would need to be resolved before closer spacings could be authorized. Therefore, it was clear that technical tests and practical demonstrations to evaluate the interactions of controllers, pilots, aircraft and procedures with the new equipment would be required to collect the necessary data and resolve ancillary issues.

In designing the demonstration, a primary goal was to provide opportunities for members of the aviation community to participate in the development of the testing program. Many of the procedures which are in place in the aviation system today did not derive from theoretical studies, but evolved through practical experience. Although there is a theoretical basis for the assumed safety and capacity improvements of the PRM, it was also considered vitally important to reap the benefit of the practical experience available in the aviation community. Comment was sought throughout the program from FAA officials, air traffic controllers, pilots, airlines, and airport authorities. The comments were used to create and to modify the demonstration plan.

1.2.2.1 Blunder Scenario Development

The PRM is designed to assist in resolving blunders, but how well it performs is heavily dependent on just what blunder scenario is selected. Of particular interest is the blunder angle. To create a collision, the blundering aircraft has to move across the spacing between the runway centerlines, and the further it turns, the faster it will move to the other side. Participants in this study agreed to use the same "worst case" blunder scenario as in earlier studies. This scenario assumes that an aircraft turns 30 degrees off the localizer toward the other parallel approach course. After such a 30-deg turn, a jet aircraft at approach speed would move toward the other runway at about 120 ft per second. The worst case scenario also assumes that the blundering aircraft ignores any controller instructions to return to course.

In designing the demonstration, a number of blunders were staged at the worst case 30-degree angle, and at a less severe 15 degrees. These were staged at various points during the approach, and during dual missed approaches. Additional blunders were staged to reflect the following situations:

1.2.2.1.1 Turbulence

With live aircraft, the blunders were staged in whatever VMC weather conditions existed when the demonstrations were scheduled. For the simulations, the blunders were staged in both calm and turbulent conditions. For the purposes of the simulation studies and of this report, turbulence or turbulent conditions are used to indicate winds aloft conditions that result in increased flight technical error. These conditions affected the flight path variability which the controllers saw in monitoring non-blundering aircraft, requiring

in turbulence, that the controller differentiate between variations in flight tracks due to turbulence, and those due to incipient blunders.

1.2.2.1.2 Runway Misidentification

If a flight crew descends below the cloud layer on a closely spaced parallel approach and sees the adjacent parallel runway rather than their own, a blunder can be created as they deviate from their approach path towards the other runway. The mistake may be due to a crosswind correction or approach lighting differences. A test scenario was included to assure that controllers can recognize this particular blunder and take appropriate corrective action.

1.2.2.1.3 Fast/Slow Aircraft

If an air carrier aircraft suddenly blunders toward a slower aircraft on the other approach, the slower aircraft may not be able to turn and escape fast enough to assure safe separation. This issue has been addressed in a test scenario.

1.2.2.1.4 Transponder Failure

The PRM is dependent on the aircraft transponder for detection and display of aircraft to the controller. If an aircraft without an operating transponder arrives at an airport where a PRM is monitoring ILS operations, air traffic control (ATC) will create a space in the arrival stream so that the aircraft cannot endanger another and thus will not require monitoring. If an aircraft transponder fails during a monitored approach, the controller will break that aircraft out of the approach stream. A scenario with an aircraft whose transponder fails is included in the demonstration.

1.2.2.2 Blunder Resolution

Satisfactory resolution of a blunder requires that the endangered aircraft be turned away in time to avoid a collision with the blundering aircraft. The amount of time available depends on several elements which characterize the performance of aircraft, air traffic control equipment, and their human operators. These elements can be understood from Figure 1-4, which shows a schematic diagram of a blunder. The elements are:

(a) The time used by the sensor to detect the blunder and generate an alarm.

(b) The time used by the monitor controller to recognize the alarm, decide whether a breakout instruction is needed, and determine when to issue the instruction.

(c) The time required to communicate the instruction to the pilot of the endangered aircraft.

(d) The time required for the aircraft crew to recognize the instruction and give the control inputs, and for the aircraft to respond to the control inputs and maneuver to the point where the separation between the aircraft is increasing.

(x) The lateral distance between the two aircraft at the start of the blunder.

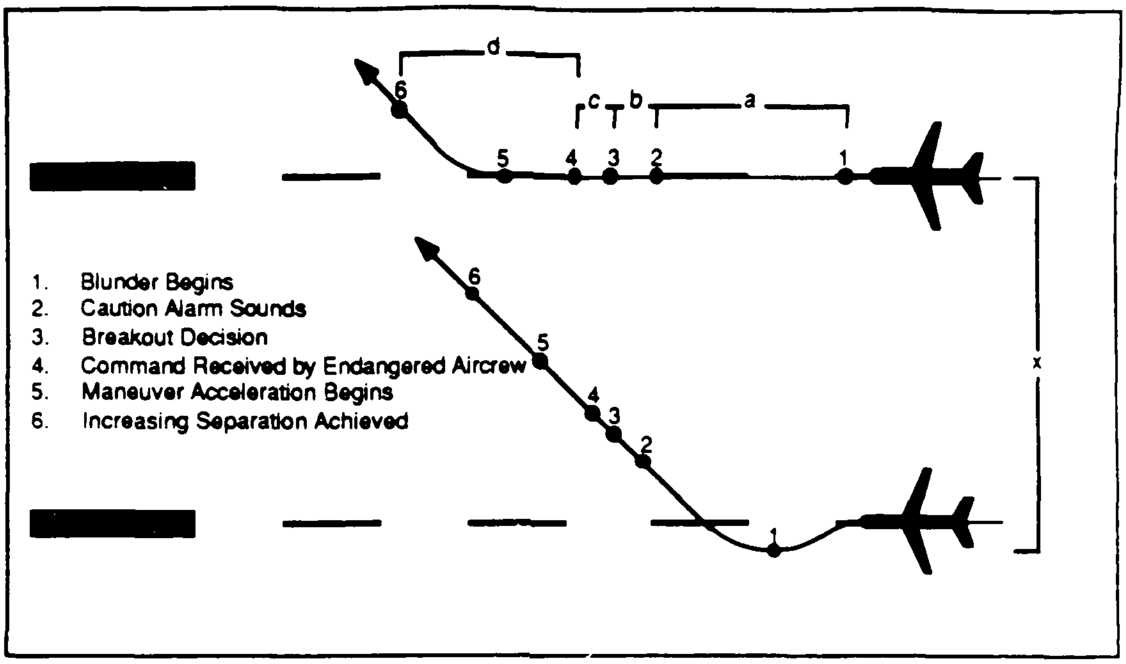

Figure 1-4. Sequence of events during a blunder.

A series of tests was conducted to study both the critical elements in blunder resolution and the overall system performance. Where possible, each of the elements was studied in isolation. Thus, the pilot/aircraft response was measured in flight simulator studies; aircraft flying normal approaches were tracked to see how closely they followed the runway centerlines; electronic timing analyses were used to determine how quickly the radars displayed targets they detected; and controllers were timed as they responded to computer simulated targets flying blunder scenarios.

It was then necessary to put all of the elements together to determine the total effect. Live aircraft, flying blunder scenarios at Memphis and Raleigh airports, detected by the PRM radars, portrayed on the displays and monitored by controllers, produced a realistic environment which could test the entire system. Because of the expense and the relative inflexibility of using the live aircraft, flight simulators flown by human pilots were interconnected with the radar displays for some of the simulations. For the live aircraft and flight simulator demonstrations, a success criteria specified that no two tracks would come closer than 500 ft before the blunder was resolved by the two aircraft diverging.

This success criteria is conservative because there is not necessarily a collision at a miss distance of 500 ft. It was chosen for two reasons: first, because the radar range accuracy and the aircraft's reported altitude will compromise the miss distance; and second because although the aircraft centers may be 500 ft apart, the wing tips are not.

In addition to the miss distance evaluations during the demonstrations, a second evaluation of total system performance was made with a mathematical model of the blunder process. This was done to understand how the variability associated with each of the blunder elements -- aircraft starting position, radar scan time, controller response, communication availability, and pilot/aircraft response -- affects the miss distance. If the worst case of each of these elements is selected (i.e., the slowest pilot response, a long

blockage of communication to the endangered pilot, the longest controller response, etc.) the system may not resolve the blunder successfully. However, it is unlikely that all of these worst case situations will occur simultaneously.

What is of particular interest is the probability that all the blunder elements will combine to produce an unacceptable miss distance. To determine this, a collision risk model was developed which simulates 100,000 blunders in the following way: for each approach, a value for each of the blunder elements is randomly selected from actual measurements taken during the demonstration. For each of the 100,000 blunders, a miss distance is computed, and from all of the miss distances, a percentage is tallied of those which are less than 500 ft.

Although this process can determine how frequently the PRM will fail to resolve a blunder, it is not known how this failure will affect the risk of collision for a typical flight. Ideally, the PRM should not add any risk to a flight, but if any risk is added, it should be negligible compared to the risk that other hazards might cause an accident on that flight. The required risk level is termed "target level of safety."

To determine the target level of safety for PRM, it is necessary to know how often blunders occur. Although participants agreed on the worst case blunder definition, there were no data on how often worst case blunders occur. Given a target level of safety, and the PRM's ability to resolve worst case blunders, it is possible to compute a maximum number of blunders per year which, if not exceeded, will assure that the target level of safety is maintained. A 30-degree blunder is sufficiently severe that most controllers or pilots having seen one will remember it. If the computed maximum blunder rate is well above anyone's recollection of actual blunders, the system can be assumed acceptable.

1.2.2.3 Ancillary Issues

Aside from blunders, several other issues requiring resolution presented themselves during discussions with members of the community as the demonstration was designed. Most of these required examination of a procedure associated with, but external to parallel approach monitoring.

1.2.2.3.1 Blocked Communications

Communication between pilots and controllers involved in a blunder situation is critical. The frequency used is the tower or local control frequency. Typical implementations of independent approaches use two local control frequencies, one for each runway, so that the controllers can speak simultaneously to two aircraft. Each monitor controller transmits on one of these frequencies, automatically overriding the tower controller. The monitor controller cannot necessarily override if another aircraft is transmitting, presumably to the tower. To take this into account, local frequency communications have been recorded at two airports during instrument conditions. The data were then used in the collision risk model to delay the controller instruction to the endangered pilot.

If the frequency is blocked for an extended period, perhaps by a stuck microphone, parallel approaches must be suspended until the frequency is cleared. The worst case blunder scenario is one result of a stuck microphone, because it calls for the blunderer not to respond to the monitor controller's instructions to return to course. The likelihood of recently stuck microphones on both monitor frequencies coincident with a blunder is extremely remote.

1.2.2.3.2 Wrong Localizer Frequency

A relatively common error for flight crews is to select the localizer frequency for the adjacent runway. If this occurs, the flight crew would be unable to intercept and track the correct localizer. This would be observed by the final approach controller, who directs the aircraft onto the localizer, before the aircraft was handed off to the tower and monitor controller. The final controller would then intervene and correct the situation prior to the start of the monitoring, or would request that the aircraft break off the approach.

1.2.2.3.3 ILS Localizer Intercept Angle

Controller procedures require that aircraft being vectored onto the localizer be given no greater than a 30-degree intercept to the localizer course as the last instruction before interception. If the rule is not observed, an aircraft may fly past the localizer course before the pilot can align the aircraft with it. Until the aircraft is stabilized on the localizer, the controller cannot authorize the aircraft to begin descent on the approach, or transfer control to the monitor controller.

1.2.2.3.4 Initial Altitude Separation

Section 1.1.1.2 discusses the requirement for altitude separation as the aircraft intercept and stabilize on the localizer. It is imperative that pilots maintain their altitude until they are stabilized, and that final controllers do not allow descent of either aircraft until both are stabilized on the correct, respective localizer.

1.2.2.3.5 Unnecessary Breakouts

An unnecessary breakout is a situation in which a controller initiates a breakout occasioned by a deviating aircraft that subsequently remains in the normal operating zone. This may occur when an aircraft behaves as though it will penetrate the NTZ and generates PRM alerts, but subsequently completes its approach without entering the NTZ. If many unnecessary breakouts occur, the system is perceived to generate too many "false alarms" and the warnings may not be believed, causing a clear safety hazard. In addition, unnecessary breakouts decrease the efficiency gains obtained by implementing independent parallel approaches. The simulation modeled aircraft behavior that might cause unnecessary breakouts, and collected data on the rate at which controllers broke out aircraft unnecessarily.

1.3 Fast Track Development Constraints

The PRM program has been conducted to minimize developmental delay and to deliver capacity benefits to operational users as quickly as possible. This "fast track" approach has meant that issues which were perceived to require extensive time for resolution have been deferred. The following sections discuss these issues.

1.3.1 Limits on Procedural Changes

The MITRE model had projected improvement by extrapolating from the current procedures and equipment. While other techniques are possible, it was believed that the fastest realization of decreased spacing would result from the fewest changes to what the operational community was comfortable with. With this in mind, choices were made early in the PRM program to limit the universe of possibilities. For example, the NTZ width was not modified, MLS curved approaches were not considered, collision avoidance logic was not proposed for the controller displays, and data-linked course corrections or traffic

displays were not proposed for the cockpit. Many of these ideas provide opportunities for further research, as identified in Chapter 9.

1.3.2 TCAS

The Traffic Alert and Collision Avoidance System II (TCAS II) is now being deployed and used by air carriers in the United States. A more sophisticated version of the system, known as TCAS III, is being developed. Initiatives have been proposed to determine the feasibility of incorporating special operational modes and features into TCAS II and TCAS III which would tailor the systems to make them useful for situational awareness during parallel approaches. Because further development of this TCAS application is required, the PRM program has sought to attain its results without reliance on a TCAS situation display. It was necessary to insure that the two systems are not incompatible, however, since TCAS will be deployed in about the same time frame as PRM.

1.3.3 Availability/Reliability/Maintainability

FAA normally requires that its air traffic control systems meet a full range of "ilities": availability, reliability and maintainability. Incorporating all of these into a production system may add significantly to the time required to develop it. Because of the large potential benefit of early PRM deployment, FAA engineers worked with the E-Scan system's developer to quickly produce a system which was deployable on an interim basis until a fully "ilities"-compliant system could be redesigned at a later time. One of the proposed implementations of the back-to-back system is as a modification to a fully compliant National Airspace System (NAS) sensor. Additions to that system may also make "ilities" compromises.

1.3.4 Integration with Existing Air Traffic Control Systems

In order to provide an appropriate monitor display for the controller, the PRM system requires access to flight identification information that is available only from Terminal Radar Approach Control (TRACON) computer systems or from the Area Control Facility (ACF). The PRM obtains this information from the TRACON via a connection to the Automated Radar Terminal System (ARTS) computer. An interim ARTS IIIA interface has been developed for that purpose. Interfaces to other models of ARTS, further integration into model IIIA, and the integration of the PRM into planned replacements of the ARTS have been deferred.

1.4 Demonstration Site Operations

The Raleigh PRM system was installed during 1988 and early 1989. Activities included installation of the sensor, associated displays, and remote connections to flight simulators at the FAA Academy and at American Airlines facilities. By May 1989, all PRM equipment was installed and the remote flight simulators successfully interconnected.

The back-to-back experimental sensor development began in April 1987, was tested at MIT Lincoln Laboratory in April 1988 and installed at Memphis in July. Engineering tests began in August. Flight technical error data were collected at Memphis during IMC weather from December 1988 through July 1989. The data were used to characterize ILS approach accuracies and develop realistic simulation scenarios. Federal Express pilots and aircraft participated in a special test to determine whether hand flying or autopilot operation significantly affects localizer deviations (Chapter 3).

A blunder demonstration rehearsal using live aircraft was conducted in July 1989 at Raleigh. The first live flight demonstrations were conducted for Congressional staffers at both Memphis and Raleigh in August.

Much activity during the fall of 1989 was in preparation for air traffic controller evaluations in 1990. A controller core group staffed by personnel from the Raleigh and Memphis Towers was responsible for the final design of the display format and the automatic alert logic. The core group worked to develop realistic test scenarios for the controller evaluations. The formal controller tests began in January 1990. By July, a total of 50 controller teams had been given orientation, training and debriefing on the PRM demonstration systems at either Raleigh or Memphis. The tests included active controllers from Raleigh, Memphis, and other U.S. facilities to collect data on the effectiveness and desirability of the PRM systems (Chapter 4).

Live blunder demonstration test flights were flown in June 1990, six days each at Raleigh and at Memphis. Two FAA aircraft participated in these live flights: a Boeing 727 and a Convair 580. A combined total of nearly 300 approaches were flown, with participation by more than 50 pilots from the airline industry.

Visitors at the two sites included representatives of the National Business Aircraft Association (NBAA), Air Line Pilots Association (ALPA), Air Transport Association, the International Civil Aviation Organization (ICAO), and numerous airport managers, associations, and consultants. FAA personnel included the Administrator, Executive Directors, and Associate Administrators. Visitors from the Memphis general aviation community were given a presentation at an accident prevention meeting and many took advantage of follow-up site tours on two weekends. Foreign delegations from Germany, Canada, Australia, China, and France visited for demonstrations and briefings. Congressional representatives visited in groups and individually to observe the system. Since operations began, 389 visitors have registered at the Raleigh site, and 622 have registered at Memphis.

2. PRECISION RUNWAY MONITOR SYSTEMS

Highlights

- **Both E-Scan and back-to-back radars yield better than 1-milliradian accuracy, have a radar processing delay of 0.5 to 1.0 second, and monitor through the approach and missed approach areas.**
- **The E-Scan radar provides an update interval as small as 0.5 seconds, while the back-to-back update interval is 2.4 seconds.**
- **The preferred sensor location is between the parallel runways at an elevation that provides a clear view over the approach and missed approach flight paths for parallel approaches.**

This chapter describes the PRM system electronics. Each PRM system consists of a radar, a display for the controller, and the ancillary display and communications gear. The precision, color, predictive displays are substantial improvements over systems in use today. The radar is similarly improved, updating at shorter intervals and higher accuracy than radar systems in use today. It is the radar which differentiates the E-Scan PRM that was demonstrated at Raleigh, from the back-to-back PRM that was demonstrated at Memphis.

System designs began from a list of operational requirements from FAA's Air Traffic Requirements Service, listed in Section 2.1. Two engineering model demonstration systems were built to exhibit most of the performance characteristics of a commissionable system, but without required reliability, maintainability, and availability. The demonstration systems are described in this chapter, as are the characteristics that distinguish them from systems which could be commissioned.

2.1 Air Traffic Service PRM Requirements

The following sections describe the air traffic control requirements that must be met by the radar monitoring system. The column on the left shows the requirements as stated for the demonstration. The right hand column presents the final requirements as adjusted for the experience gained during the demonstration.

System Description:	System Description:
The PRM will be a high resolution sensor capable of providing a monitor controller with a clear, accurate presentation of aircraft conducting precision approaches independently to parallel and/or converging runways in all weather conditions.	The PRM will be a high resolution sensor capable of providing a monitor controller with a clear, accurate presentation of aircraft conducting precision approaches independently to parallel runways in all weather conditions.

Operational Requirements:	Operational Requirements:
1. The PRM system shall be capable of providing coverage at the subject airport for all parallel runways and converging runways which have a parallel or converging approach application. This requirement may be satisfied by multiple sensors capable of presenting all data (and/or any part) on a common display.	1. The PRM system shall be capable of providing coverage at the subject airport for all parallel runways which have a parallel approach application. This requirement may be satisfied by multiple sensors capable of presenting all data (and/or any part) on a common display.
2. Elevation coverage shall extend from no higher than 50 feet above the airport surface to at least 1,500 feet above the highest initial approach altitude for any ILS/MLS approach to be used.	2. No change.
3. Range coverage shall extend to 15 nmi from runway end on the final approach course continuous to 5 nmi beyond approach end on the departure/missed approach side of the airport.	3. Range coverage shall be up to 30 nmi from runway end on the final approach course continuous to 5 nmi beyond approach end on the departure/missed approach side of the airport.
4. Azimuth coverage shall extend from at least 1,500 feet outside the outboard parallel/converging runways final and missed approach courses to include all airspace in between.	4. Azimuth coverage shall extend a minimum of 2 nautical miles either side of the parallel/converging runways final approach paths continuous through the missed approach courses.
5. The area of non-return around the sensor shall not adversely affect controller capability to monitor final or initial missed approach courses.	5. No change.
6. Sensor accuracy shall be verified to ensure correlation of target symbology with actual aircraft position, assuming the aircraft equipment has zero error.	6. No change.
7. Independent displays shall be provided to each monitor position.	7. Independent displays shall be provided for each monitor position. However, for availability purposes, a single display may be used for two monitor positions.
8. System capacity shall be at least 25 tracked targets.	8. System capacity shall be at least 25 tracked targets for parallel runways, 35 for triples, and 50 for quadruples.

9. System reliability shall be at least equivalent to existing ASR monitor systems, including uninterrupted power source and fail safe capability (all display data retained when changing power source).	9. No change.
10. System failures which compromise safety of the PRM shall generate a visual alarm on the display, as well as, an aural signal. In the event of a system overload or partial failure, an appropriate message shall be generated and displayed for the controller. The system shall not "bomb out," but will drop data based on its relative importance, temporarily reduce range, or otherwise allow the system to recover. Tracked targets shall not be affected.	10. No change.
11. Tracked target recording, replay, and simulation shall be a capability.	11. No change.
12. System update rate, throughput time, resolution and display presentation shall enable a monitor controller to detect tracked target deviations from a course of 100 feet or less.	12. Resolution and display presentation shall enable a monitor controller to detect tracked target deviations from a course of 100 feet or less.
13. The display shall be at least 18 inches in diameter or diagonally, and the console shall not exceed the size of current air traffic ARTS consoles.	13. No change.
14. All operator controls and keypack units shall be immediately accessible to the user.	14. Each monitor position shall have operator controls and keypack units immediately accessible to the user.
15. The display shall have full variable range and offset capability. Display presentation quality shall recover within one second after range change or offset.	15. No change.
16. The display presentation shall provide sufficient contrast and brightness under normal TRACON ambient light conditions and must be free of reflection and glare.	16. No change.

17. Display presentation quality shall be constant throughout the display area, clear of clutter, flicker free, of uniform brightness, and well defined with no blooming.	17. No change.
18. There shall be no evidence of false targets or other spurious returns on the display.	18. The system shall be relatively free of false targets or other spurious returns on the display.
19. Display mapping capability shall be available for selection by the controller. Line widths and any associated alphanumerics shall be as small as practicable with variable intensity. Mapping shall include as a minimum:	19. No change.
a. Runway outline of all runways within the coverage area of the PRM system.	a. No change.
b. A broken line in one-nautical mile increments representing the final approach course to each runway to be used for simultaneous approaches.	b. A broken line in half- or one-nautical mile increments (site selectable) representing the final approach course to each runway to be used for simultaneous approaches.
c. Final approach fix and other appropriate fixes as displayed on the ARTS display.	c. No change.
d. Prominent obstructions.	d. No change.
e. A no transgression zone (NTZ) 2,000 feet wide located equidistant between parallel runway centerlines.	e. No change.
f. The normal operating zone (NOZ) is that area between runway centerline (extended) and the closest edge of the NTZ. The NOZ shall be clearly distinguishable from the NTZ and display in increments of 100 feet.	f. The normal operating zone (NOZ) is that area between runway centerline (extended) and the closest edge of the NTZ. The NOZ shall be clearly distinguished from the NTZ and display in increments of 200 feet.

20. Tracked targets shall automatically display associated ARTS data block information including low altitude and conflict alert when appropriate. Character size, intensity, data block offset, leader line length, and field inhibit shall be controller selectable at each display.	20. Tracked targets shall automatically display associated ARTS data block information including low altitude and conflict visual alerts when appropriate. Character size, intensity, data block offset, leader line length, and field inhibit shall be controller selectable at each display.
21. Controllers shall have the capability to start or drop tracks at each display, and to filter out targets by altitude or geographic location.	Deleted
22. Target symbology on the largest setting shall not exceed the approximate size of a large (B-757) type aircraft, and shall represent the most recent return for each tracked target, corrected for altitude if possible.	21. Target symbology on the largest setting shall not exceed the approximate size of a large (B-757) type aircraft, and shall represent the most recent return for each tracked target.
23. Tracked target symbols shall have a track history displayed variable in intensity and from 0-16 hits, from the control keyboard or console.	22. Tracked target symbols shall have a track history displayed that shall be variable in intensity and in length from 0-16 hits. It shall also be controllable from the keyboard or console. The use of this feature shall be optional on the controllers part as directed by procedures.
24. Tracked target symbols shall have a projected track vector generated from track history and ground speed, and then displayed as a keyboard or console controlled variable length line.	23. No change.
25. A track projected to enter the NTZ in (N) target updates shall uniquely change to alert the controller, (flashing data block, color change etc.). The number of track updates for this alert shall be programmable from 0-16.	24. A track projected to enter the NTZ in 10 seconds shall uniquely change to alert the controller (flashing data block, color change etc.). This number of seconds shall be programmable from 0-16.
26. A distinctive, unique audible alert shall sound only at the monitor position when a track touches or enters the NTZ. This alarm shall have an on/off volume control at the position.	25. A distinctive voice alert shall sound only at the monitor position when a track is projected to enter the NTZ. This alert shall have a controllable volume switch at each operational position.

27. A track deviation from centerline of (N) feet, or infringement into the NTZ shall generate a printout of track data (data block information etc.).	26. Track deviations which infringe into the NTZ shall generate a printout of track data (data block information, etc.). System parameter changes shall also generate a printout.
28. A means shall be provided to enable monitor controllers to observe traffic and/or weather in the immediate vicinity of final monitor airspace.	Deleted
	27. The PRM system shall have a passive ARTS interface.

2.2 E-Scan Radar

The E-Scan radar consists of a stationary, cylindrical, phased array antenna, an interrogator and a surveillance processor. The sensor uses a monopulse azimuth measurement technique, providing an accuracy better than 1 milliradian (0.06 deg). The interrogator and surveillance processor schedule interrogations and track targets based on replies from a minimum of 25 targets at a one-second update interval and 15 targets at a half-second update interval. It can operate at update intervals up to 5 seconds.

2.2.1 Tests

Laboratory checkout, antenna test range tests and site integration testing culminated in proof of performance testing at Raleigh during Spring, 1990. The tests were supported and witnessed by personnel from the FAA Technical Center.

The testing was structured to demonstrate each paragraph of FAA's ACP-5-12K specification [3]. The tests were grouped into four major categories according to the test equipment and the test environment required:

(a) Equipment tests, to establish performance of transmitter, receiver, and antenna subsystems using laboratory type test equipment. An FAA approved test plan was followed, including data logging and witnessing procedures.

(b) Surveillance tests, to show resolution, accuracy, and proper reply detection using calibrated transponders (Parrots) at known ground positions. The results were based on statistical analysis, visual inspection of reply data and, where appropriate, observation of the displays during operational use.

(c) Display tests, to demonstrate features of the display using targets of opportunity, aircraft simulator targets, digital tape recorders and graphics display menus. The features were verified while operating the display according to the operational handbook.

(d) Flight checks, to verify performance, target resolution and target accuracy using controlled aircraft flights, high precision trackers and analysis of recorded data.

Analysis verified an azimuth accuracy of 0.9 milliradians Root Mean Square (RMS) and an update interval which can be varied from 0.5 to 5 seconds. The sensor correctly resolved proximate aircraft pairs, provided 99.9% target report reliability with correct code data for proximate targets on final approach, 98.2% for targets of opportunity within 10 nmi, and 99.8% for targets on approach and missed approach. The sensor also met all coverage requirements, and tracked 22 targets (the maximum number of aircraft available during the tests) at a 1-second update interval without exceeding computer processing limits. Buffering of target data and the display driver implementation chosen for the demonstration system caused a total cumulative delay through the entire system to be just over 1.5 seconds when 25 targets were in track. This system processing delay limitation will be alleviated when the system is upgraded for operational use.

A proof of performance final report [4] contains the test procedures and witnessed results.

2.2.2 Demonstration Site

The demonstration system antenna site was located near the center of the Raleigh airport, centered between the two runways on a 75-ft steel tower. This is sufficient to interrogate aircraft on all four precision approaches without obstruction from airport structures except the control tower. It covers both final and missed approach paths.

The control tower is 313 ft from the antenna. The 200-ft tall, 44-ft diameter tower produces an 8-degree shadow in the coverage volume centered on 335 degrees azimuth from true north. In addition, diffraction on either side of the tower causes significant angular error out to 3.5 degrees around the shadowed angles and specular reflections produce noise-like angular errors inside a 2-nmi range. These errors have little effect on tracking and blunder detection for targets not in the 15-degree zone about the control tower.

2.2.3 Upgrade System

The E-Scan demonstration sensor is being upgraded so that it can be certified for operational use. The sensor will be functionally identical to the demonstration unit. The upgrade will provide (a) additional performance monitoring, (b) a second, standby, interrogation and surveillance processing subsystem that will be automatically activated if a failure is detected in the active subsystem, (c) improved protection of the antenna, (d) upgraded processing capability to meet surveillance delay and capacity requirements, and (e) maintenance adjustments and monitors for the facilities personnel. As discussed in Section 1.3.3, FAA and MSI chose to make some compromises in normal FAA "ilities" requirements to bring the E-Scan technology into use as rapidly as possible.

2.3 Back-to-Back Radar

The back-to-back system uses a mechanically rotating antenna. Two 5-ft open array beacon antennas rotate at conventional airport surveillance radar (ASR) rates, to yield an update interval half that of the ASR. Monopulse processing of the returns yields an accuracy of 1 milliradian.

For the demonstration, an experimental monopulse sensor, originally developed as a portion of the engineering model for the FAA's Mode S system, served as an interrogator and surveillance processor. Two antennas were mounted on a modified ASR-7 pedestal and rotated at a nominal 4.8-second period for a 2.4-second update interval. Full operational implementation of back-to-back antenna surveillance requires two interrogators, but only one was available for the demonstration. To mimic a second interrogator, the

available unit was switched between antenna faces as the antenna rotated. A 120-degree sector was chosen for coverage of both faces. The back-to-back demonstration system was located on a 35-ft tower between the thresholds of Memphis runways 36L and 36R. The 120-degree limitation, coupled with the sensor location, permitted coverage of both approach and missed approach courses for south operations at Memphis but did not cover the missed approach for north operations. Limitations in the processing speed of the surveillance computer chosen for the demonstration restricted the interrogation rate during peak traffic periods.

2.3.1 Tests

The single antenna performance of the Mode S sensor was extensively tested during original development at Lincoln Laboratory, and during the subsequent FAA Technical Center testing of engineering models built by Texas Instruments prior to the awarding of the production contract. Back-to-back antenna performance in the 10-to 12-second en route mode was evaluated at Elwood, New Jersey. Since then, the monopulse surveillance design within the Mode S sensor has been reviewed and adopted by several other International Civil Aviation Organization (ICAO) states and is now operational in the United Kingdom and in continental European countries.

A significant test activity to characterize the surveillance performance was completed during the 1970's when the transportable measurement facility (TMF), a portable Mode S sensor with extensive instrumentation, was deployed to sites within the continental United States. At each site, the TMF measured the monopulse and Mode S surveillance performance over a wide variety of traffic densities and multipath conditions. Among the 14 locations were Los Angeles, Boston, Philadelphia, Washington, DC, Las Vegas, and Salt Lake City. Simultaneous recordings of ARTS data were made in order to assess the performance benefits of the monopulse surveillance. The results of this activity have been previously documented [5].

Since back-to-back sensor performance had been previously characterized, performance testing at Memphis was limited to issues that are specific to the PRM application. The specific issues were back-to-back operation at a 4.8-second mechanical scan period, sensor coverage, accuracy, and reliability within a few nautical miles of the antenna, particularly on and just above the airport surface. These requirements were not emphasized during the original Mode S development, except for provisions to detect and eliminate false target reports due to fixed reflector objects.

Back-to-back operation was evaluated using electronic switches that selected the desired antenna face for use by the sensor. Surveillance data from each face were recorded. When unanticipated bias errors occurred between the two faces, further measurements were made to characterize and develop a compensation algorithm.

A series of flight tests were made using Lincoln Laboratory and FAA aircraft to establish the accuracy and coverage limits of the sensor. The test flights also revealed a false track surveillance problem. The false tracks were the result of (a) significant transponder reply garbling in the immediate vicinity of the airport due to flight crews neglecting to place the aircraft transponders on standby while taxiing, and (b) reply reflections from taxiing aircraft, airport buildings, and vehicles on roads adjacent to the airport. Data were recorded to support the design of modifications to the surveillance software to reject the false tracks. Target of opportunity data were also collected during heavy traffic periods.

Analysis of the back-to-back demonstration system performance data in the 2.4-second mode indicated an azimuth accuracy of better than 1 milliradian RMS based on targets of opportunity. This result is consistent with the typical surveillance accuracy achieved by the monopulse azimuth estimation design imbedded in the Mode S sensor.

Surveillance data on airborne targets of opportunity indicate a target report reliability, per update interval, of 98% for proximate (garbling) targets, 99% for clear targets. To achieve this result, a more restrictive association test for discrete code targets was added to the surveillance processing subsystem to account for the presence of numerous false targets in the airport vicinity. The false targets were largely due to airport structures, taxiing aircraft and vehicles on parallel boundary roads. Code reliability was 99% for Mode A and 98% for Mode C.

Coverage was determined by relocating the active 120-degree azimuthal sector. Low approach coverage over both parallel runways was verified by means of a test aircraft. The low approach target report update reliability was about 98%. Even though the demonstration sensor target capacity was limited by the surveillance computer, it was able to track at least 25 targets in back-to-back mode, and 80 in single antenna mode. An operational Mode S sensor is specified to handle 700 aircraft in a standard en route 12-second back-to-back configuration. It is reasonable to assume that a Mode S sensor in the back-to-back configuration will support the limited target load required for PRM.

The processing delay was measured to be 0.5 to 1.0 second. The production Mode S sensor is specified to provide surveillance data within 0.375 to 0.440 seconds.

2.3.2 Demonstration Site

The Memphis site has an appropriate location for a clear view of the approach and missed approach flight paths. It also has an unobstructed view of the terminal buildings, gates, taxiways and highways when measuring the location of aircraft landing on runways 18L and 18R. As a result, it is common to observe many short lived false tracks if the false target rejection software is disabled. Analysis of surveillance data indicates that airport structures, taxiing aircraft and large vehicles on adjacent roads cause most of the false tracks. This analysis is continuing so that specific criteria may be developed to aid in the selection of future sites. However, it now appears that the best location for minimizing reflection false tracks is a high central location like that at Raleigh.

2.3.3 Back-to-Back Implementation

FAA anticipates that implementation of the back-to-back PRM would be effected as a modification to FAA's production Mode S system, undergoing factory testing as this report is being written. The terminal version of the Mode S sensor is colocated with the airport surveillance radar (ASR). A Mode S sensor modified for use as a PRM would be similar to the Mode S en route sensor, a configuration that already provides for back-to-back antenna surveillance. The specific modifications to the production version of a terminal Mode S sensor for PRM are to:

(a) Add a second beacon antenna on a strengthened ASR-9 antenna mount with a more capable rotary joint,

(b) Add a third interrogator channel (two for the back-to-back surveillance, and one for a spare),

(c) Modify channel management software to schedule back interrogations at the 4.8-second period rather than the en route 10-to 12-second period,

(d) Add an additional communications output to obtain the full surveillance accuracy for the PRM displays,

(e) Add a function to correct back-to-back antenna bias error, and

(f) Make modifications to the surveillance algorithms to improve false target rejection in the vicinity of the airport.

If a Mode S sensor were to be used for PRM without the colocated ASR, there would be no need to modify the ASR-9 mount or acquire a new rotary joint. It is necessary to fabricate a mechanical interface to support the two beacon antennas on a standard mount.

2.4 Displays

2.4.1 Configuration

The displays connected to the E-Scan and back-to-back radars are functionally equivalent. The displays consist of large (20- x 20-inch), high resolution, color monitors. Monitor controllers will use PRM displays in the Terminal Radar Approach Control (TRACON) IFR room. Associated with the displays is the same communications equipment and ancillary data displays found in the plan view displays (PVD's) in use today.

During the demonstration, the displays were installed in a room separate from the IFR room, although data and communications were provided for the controller as necessary to establish a realistic environment for the demonstration. Display formats and symbologies were developed with the assistance of a "core group" of controllers at Memphis and Raleigh.

In addition to color, resolution, and size, the PRM display differs from the traditional PVD in other important ways. One of these is the ability to display a "predictor" that projects where the aircraft will be ten seconds ahead. Another is a four times expansion of the axis perpendicular to the runways compared with the axis along the runways, which has the effect of making lateral deviations more evident to the controller.

2.4.2 Automated Alert

Perhaps the most significant feature of the PRM display is the automated alert. The system provides two alerts to the monitor controller on the occurrence of flight path deviations that may be hazardous. When it predicts that the aircraft will enter the NTZ within ten seconds, the target changes from green to yellow, and an audible alert sounds. When the aircraft has penetrated the zone, the target changes to red. (At Memphis, endangered aircraft also changed to red).

The alerts are valuable because of the relative rarity of approach blunders. Monitor controllers may not see a blunder for many months and an alert will at least confirm that a blunder is occurring, and may allow the controller to notice the blunder earlier.

The alert is intended to give ten seconds warning of NTZ penetration by a blundering aircraft. The warning, termed the "caution alert lead time" (CALT), is

diagrammed in Figure 2-1. The design is a compromise between an alert which is very sensitive to a blunder and gives an early warning, sometimes unnecessarily, and an insensitive one which seldom alarms unnecessarily but sometimes fails to alert to a real blunder.

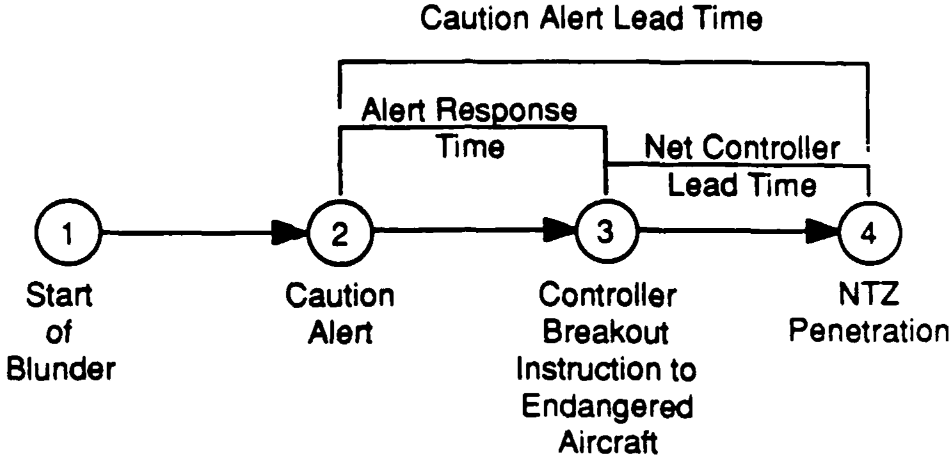

Figure 2-1. Sequence of timing events from start of blunder to NTZ penetration.

An analysis explored the performance of the algorithm under various conditions. Figure 2-2 illustrates the effects of blunder angle and range. As blunder severity increases or runway separation decreases, the alert gives less warning of NTZ penetration. Figure 2-3 shows the effect of varying radar azimuth accuracy. As accuracy decreases, tracker gains must be decreased to filter out the increased noise. But the greater the filtering, the more time required to detect the blunder. Thus, a more accurate radar allows an earlier alert. Figure 2-4 illustrates that faster radar updates also yield earlier alerts.

In all cases but one, lead time is significantly less than the 10-second design goal. This is due in part to the lag time for the tracker algorithm to adapt to the turn, and in part to the fact that the aircraft frequently continues to turn after the caution alarm is triggered, thus shortening the time to NTZ penetration. There may be some improvement in tracker response to turns by use of a different set of gains or by use of a different algorithm [6]. Currently, the two demonstration systems are using two different sets of tracker gains with an "alpha-beta" tracker. No comparison has yet been made between the two sets of tracker gains, but it is recommended that this be done as part of a standardization effort.

Late alert rate is defined as the percentage of blunders in which the aircraft entered the NTZ without a caution alert. The probability of a late alert increases with increasing radar noise or update interval and with decreasing runway separation. These trends are illustrated in Table 2-1 for a 30-degree blunder at 10 nmi. In general, this problem cannot be compensated for by adjusting the tracker gains. Increasing tracker sensitivity will concomitantly decrease the late alert rate and increase the unnecessary alert rate. It is very difficult, for runway separations less than or equal to 3,400 ft, to achieve a rate of less than five percent for both unnecessary alerts and late alerts for radars with RMS azimuth error greater than 1 milliradian.

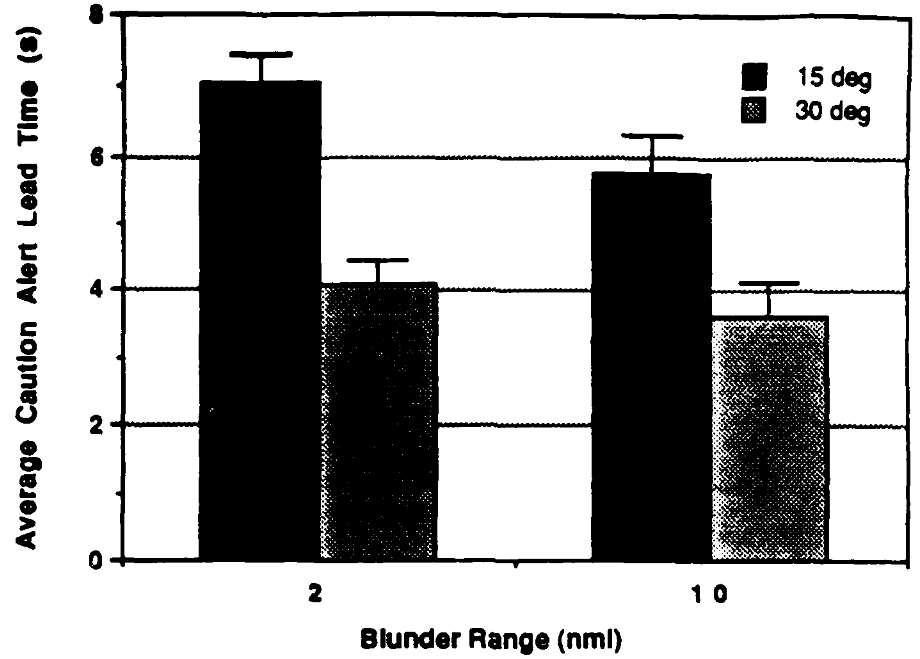

Figure 2-2. Effect of blunder heading and range on average caution alert lead time. Runway separation: 3,400 ft, azimuth accuracy: 1 milliradian, update interval: 1 s. Error bars represent one standard deviation.

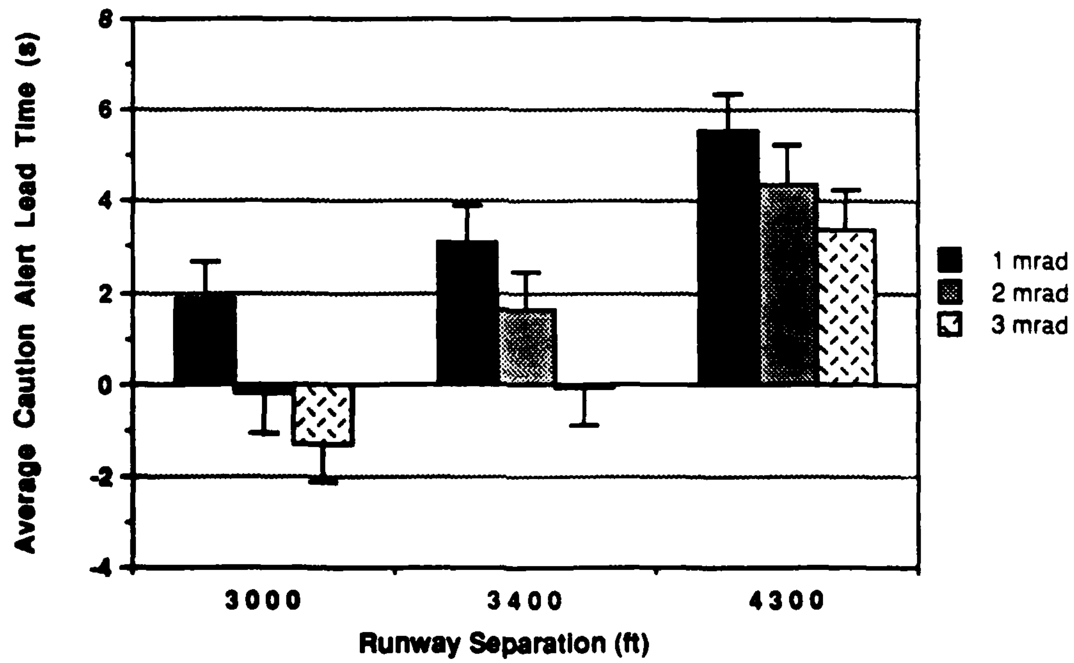

Figure 2-3. Effect of azimuth accuracy on average caution alert lead time. Update interval: 2.4 s, blunder heading: 30 degrees, blunder range: 2 nmi. Error bars represent one standard deviation.

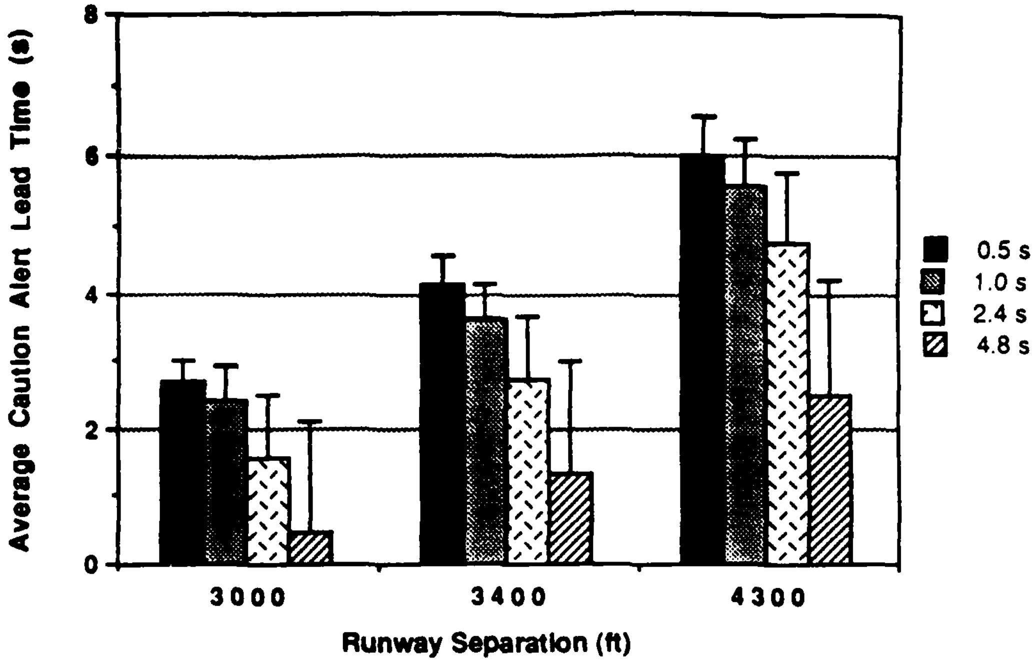

Figure 2-4. Effect of update interval on average caution alert lead time. Azimuth accuracy: 1 milliradian, blunder heading: 30 degrees, blunder range: 10 nmi. Error bars represent one standard deviation.

Table 2-1

Percent late alarm rate. Blunder: 30 deg at 10 nmi.

Separation (ft)	Update (s)	Azimuth Accuracy		
		1 mrad	2 mrad	3 mrad
3,000	0.5	0	21.8	99.9
	1.0	0	44.4	98.6
	2.4	4.3	64.9	98.5
	4.8	39.2	79.0	97.1
3,400	0.5	0	0	22.3
	1.0	0	0	35.8
	2.4	1.4	9.0	62.2
	4.8	21.7	46.8	79.3
4,300	0.5	0	0	0
	1.0	0	0	0
	2.4	0.1	0.1	1.4
	4.8	4.8	9.0	22.1

2.4.3 ARTS IIIA Interface

An Automated Radar Terminal System (ARTS) computer interface allows PRM access to ARTS flight data. The interface operates by passively monitoring data sent from the ARTS to a Data Entry and Display System (DEDS), typically the maintenance display. The ARTS software is modified to substitute Air Traffic Control Radar Beacon System (ATCRBS) Mode A code for ground speed in the data tags sent to the particular display that is monitored by the ARTS interface. Through the interface, PRM is provided with flight ID, aircraft type, Mode A and Mode C codes, ARTS scratch pad, heavy indicator, and conflict/minimum safe altitude warning (MSAW) alerts.

2.4.4 Data Recording System

A data recorder in the operational PRM system will record surveillance data from the radar and caution and warning outputs from the automation logic. Other PRM system inputs deemed important may also be recorded. Audio recordings of new local radio frequencies will be provided by the recording system presently installed in the TRACON equipment room.

2.5 Radar Location Impact

The location of the PRM radar is critical to the performance of the sensor. There are three principal concerns: obstructions to the flight paths, susceptibility to multipath induced false tracks, and effect of range bias.

2.5.1 Flight Path Obstruction

Controllers are required to observe aircraft during all likely missed approach flight paths. The PRM sensor must therefore have unobstructed views of aircraft flying as low as fifty feet above all active parallel runways.

2.5.2 Multipath Induced False Tracks

False tracks have been observed at Memphis and Raleigh that are due to reflections from the control tower, terminal buildings, fuel tanks, taxiing aircraft and large vehicles on adjacent boundary roads. These tracks, though of short duration, can seriously disrupt the surveillance data provided to the monitoring display. Several surveillance design enhancements have been developed to reduce the impact of this phenomena. However, it is clear that the surveillance is also significantly improved if the sensor antenna is located near the center of the area defined by the parallel runways of interest and as high as possible. Additional analysis to develop specific recommendations on site locations to mitigate against false tracks due to multipath will be completed during early 1991.

2.5.3 Effect of Range Bias

The effect of radar location on the lead time was studied by modifying the analysis model used for Section 2.4.2 so that the radar location varied from 2,000 ft outside the blundering aircraft's approach path to 7,000 ft in the direction of the adjacent approach path. Runway separation was 3,400 ft, azimuth accuracy was 1 mrad, and update interval was 1.0 s. The study simulated 30-degree blunders at either 2 nmi or 10 nmi from the radar and measured the caution alert lead time (CALT).

For blunders at 2 nmi from the radar, the mean CALTs were the same, but the spread of the distributions varied with radar location. The smallest standard deviation

occurred when the radar was 1,000 ft inside the blunder approach path, while the largest standard deviation was for the radar location 7,000 ft in the direction of the adjacent approach. The primary contributor to the variation in CALT is range bias caused by variations in transponder turn-around delay times. When the radar is located in the vicinity of the airport, range bias affects performance of the caution alert for aircraft near the runway where radar range makes a significant contribution to the off-centerline position measurement. For aircraft further from the runway, the measurement of off-centerline position is primarily an azimuth measurement and range bias is less important to CALT. Thus, for blunders at 10 nmi, the location of the radar did not significantly affect performance of the caution alert: mean CALTs and standard deviations were similar.

Since a blunder could occur on any parallel approach path, a radar site midway between the parallel runways would minimize the variation in CALT due to radar error for all four possible approach paths.

2.6 Transponder Failures

The PRM radar is a beacon system and therefore depends on the reliability of aircraft transponders. If an aircraft transponder fails, the surveillance accuracy provided by the PRM is lost and a simultaneous independent approach at runway separations less than 4,300 ft cannot be authorized for that aircraft. If transponder failures are a common occurrence, PRM operations would be adversely effected.

In order to evaluate how likely a transponder failure is, the final approach data collected at Memphis were examined for transponder failures. Out of over 7,000 arrivals, there were only 8 flights that were believed to have had serious transponder problems that caused PRM surveillance to be lost or significantly degraded: three DC9s, one B727, one L188, one C172, one DA20, and one unidentified general aviation aircraft. This rate of about 0.1% transponder failure is low enough that it can be handled procedurally without significant impact on PRM monitoring of simultaneous independent parallel approaches.

3. ILS FLIGHT TECHNICAL ERROR

Highlights

- **For 3,400-ft runway spacing, flight technical error (FTE) results in significant numbers of aircraft in the NTZ beyond about 10 nmi from the runway threshold. For 2,000/3,000-ft glideslope intercept, the NTZ begins just inside 10 nmi.**
- **There are a number of possibilities for reducing FTE, should that be required for closer runway spacings.**
- **The older generation of autopilots, which includes most in use today, provides no advantage over hand flown approaches. More advanced autopilots available in air carrier aircraft built in the last 5-10 years perform better.**

Aircraft navigate laterally during ILS approaches by receiving the localizer signal. Although the localizer is one of the more precise navigational signals in use today, aircraft flying with its guidance are subject to errors from several sources, including the accuracy of the signal at any point in space, the accuracy of the aircraft receiver and display, and the ability of the pilot to fly the airplane in response to the display. For the purpose of this report, the aggregate error from all of these sources is called flight technical error (FTE). The FTE expresses how close to the localizer course an aircraft may be expected to remain, assuming that the pilot is doing his best to stay on the centerline. Most components of FTE are angular, so the linear distance away from the centerline due to FTE increases as the distance from the aircraft to the localizer antenna increases.

With parallel runways, FTE is of more concern, and the closer the spacing, the greater the concern. FTE alters the separation which would be assumed if the aircraft were on centerline. This will increase separation if the aircraft are off centerline away from the other runway, or decrease it in the opposite case. Decreased separation means less time to resolve a blunder.

FTE also contributes to unnecessary alerts and breakouts. For closely spaced runways, increased FTE for aircraft near the glideslope intercept will cause some non-blundering aircraft to penetrate a small distance into the NTZ. In the absence of controller intervention, these aircraft will return to the appropriate NOZ and land successfully without endangering any other aircraft. However, the monitor controller has little choice but to break out an endangered aircraft when a nearby aircraft penetrates the NTZ, and FTE therefore increases unnecessary breakouts.

Since this may present a serious constraint to simultaneous ILS operations, a measurement program was undertaken to characterize lateral FTE during normal approaches to parallel runways. Measurements were taken at Memphis as part of the PRM project, and at Chicago under another project. The data were collected during dependent parallel approaches at Memphis (runway spacing 3,400 ft), and under simultaneous independent approaches at Chicago (runway spacing greater than 4,300 ft).

3.1 Data Collection

3.1.1 Memphis

The PRM test facility at Memphis was provided with extensive instrumentation to measure and characterize FTE. Surveillance, weather, and flight data were collected during periods of busy arrivals. The PRM sensor collected surveillance data with an accuracy not available in previous studies. Weather data included airport surface observations, predicted winds aloft, and additional ceiling measurements taken from laser ceilometers located at the north and south ILS outer markers. Flight identification (ID), aircraft type, and runway assignment were obtained through an interface to the FAA ARTS computer system. The data collection was monitored by site personnel during each data collection period in order to note system parameters and atypical events.

Data were collected from 11 January to 15 November, 1989. There were 162 data collection periods that recorded 7,333 arrivals. Instrument meteorological conditions (IMC) prevailed 27% of the time, marginal visual meteorological conditions (VMC) 30%, and visual meteorological conditions 43%. Only one data collection period had significant surface crosswinds. The majority of the aircraft observed were "large" aircraft (between 12,500 and 300,000 pounds). Figure 3-1 shows the distribution of aircraft types in the collected data.

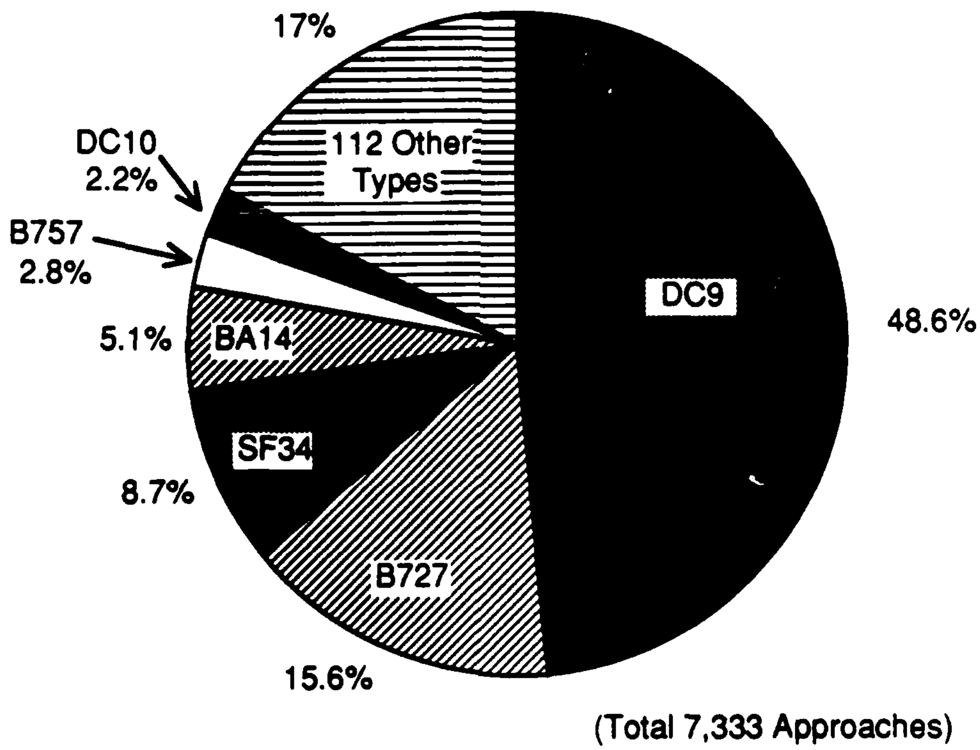

Figure 3-1. The distribution of aircraft types in the Memphis final approach database.

3.1.2 Chicago

The FAA Technical Center collected ILS approach data on independent arrivals to the parallel runways at Chicago's O'Hare International Airport [7]. The Chicago data provided an independent assessment of FTE, and made possible an assessment of any differences between dependent and independent parallel approaches.

The data collection took place 24 January to 14 March, 1989. Over 3,000 simultaneous approaches were recorded. The ASR-7 (Airport Surveillance Radar) and associated beacon radar provided the surveillance. Other data collected included flight ID, and weather observations made from the airport surface. Audio recordings were also made of controller/pilot communications. The methods and results of the FAA Technical Center study are described in a separate report [7].

3.2 Data Analysis

Analysis of the Memphis and Chicago FTE data allows characterization of FTE on parallel approaches. In the analysis of Memphis FTE data, several steps were used to select only the aircraft tracks of interest. First, the aircraft had to be "established" on the localizer, a requirement for monitoring to begin. An aircraft was considered to be established after it had flown one nautical mile past the point where it came within a one-degree angle of the localizer centerline and remained within the one-degree angle until landing. Second, the aircraft had to be "established" on the localizer before that aircraft (or its neighbor on the adjacent parallel course) intercepted the glideslope -- 9.4 nautical miles from the runway threshold at Memphis. Finally, only the tracks flown in IMC by aircraft over 12,500 pounds were included. IMC is classified as weather conditions providing surface visibility less than or equal to 3 statute miles or a cloud ceiling at or below 1,000 ft above ground level. Figure 3-2 shows the track segment selected for a typical aircraft. A similar selection algorithm used on the Chicago data is described in a separate report [7].

3.2.1 Memphis

The Memphis data are presented in four plots. The statistics and analyses shown are based on data combined from the four Memphis parallel approach courses. A positive deviation indicates motion toward the other parallel runway. First is Figure 3-3, a density plot of centerline deviation versus range from the runway threshold for approaches carried out while instrument flight rules (IFR) were in effect. The figure includes lines drawn one degree to either side of the extended runway centerline and a dotted outline indicating where the NTZ would be if simultaneous independent approaches were being conducted with glideslope intercepts at 2,000 and 3,000 ft or 3,000 and 4,000 ft. Only aircraft that met the selection criteria described previously are included.

The second plot, in Figure 3-4, shows FTE means and standard deviations calculated within each 0.2-nmi range interval from 1 to 15 nmi. The standard deviation increases with range, as might be expected from the angular nature of the errors. The mean centerline deviations have a small but definite trend away from the NTZ that increases with range. At 10 nmi the mean deviation from centerline is 58 ft away from the NTZ. Although the cause of the non-zero means is not known, it may be that pilots, who knew parallel approaches were in progress, avoided displacements toward the adjacent parallel runway. The standard deviation as a function of range is one of the inputs to the collision risk model. This input was provided by making a linear fit to the standard deviation data from 1 to 11 nmi from the runway threshold (Figure 3-5).

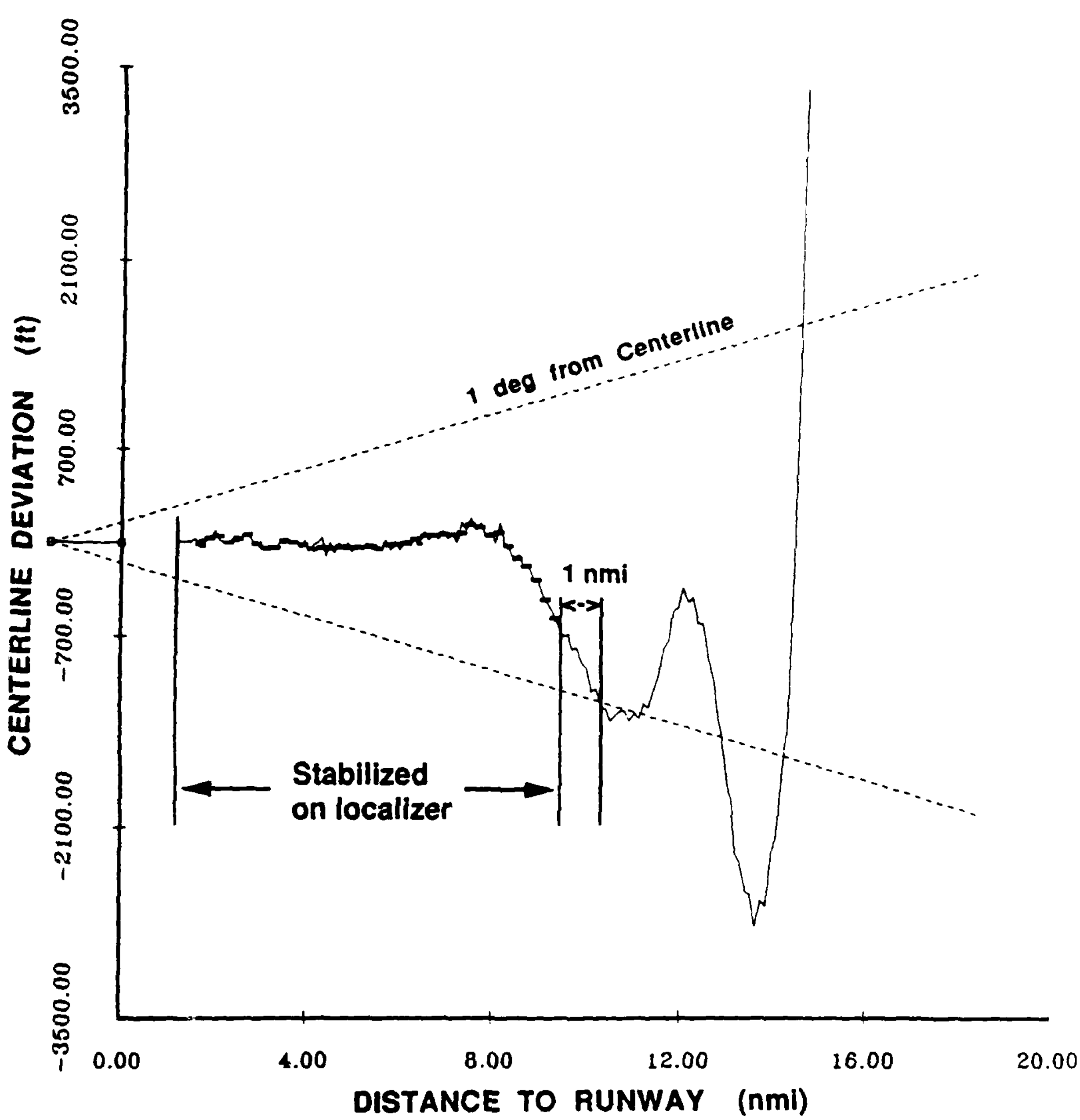

Figure 3-2. Stabilized segment of a sample approach into Memphis International Airport. The small boxes along the radar track represent the array bins that are incremented with these data.

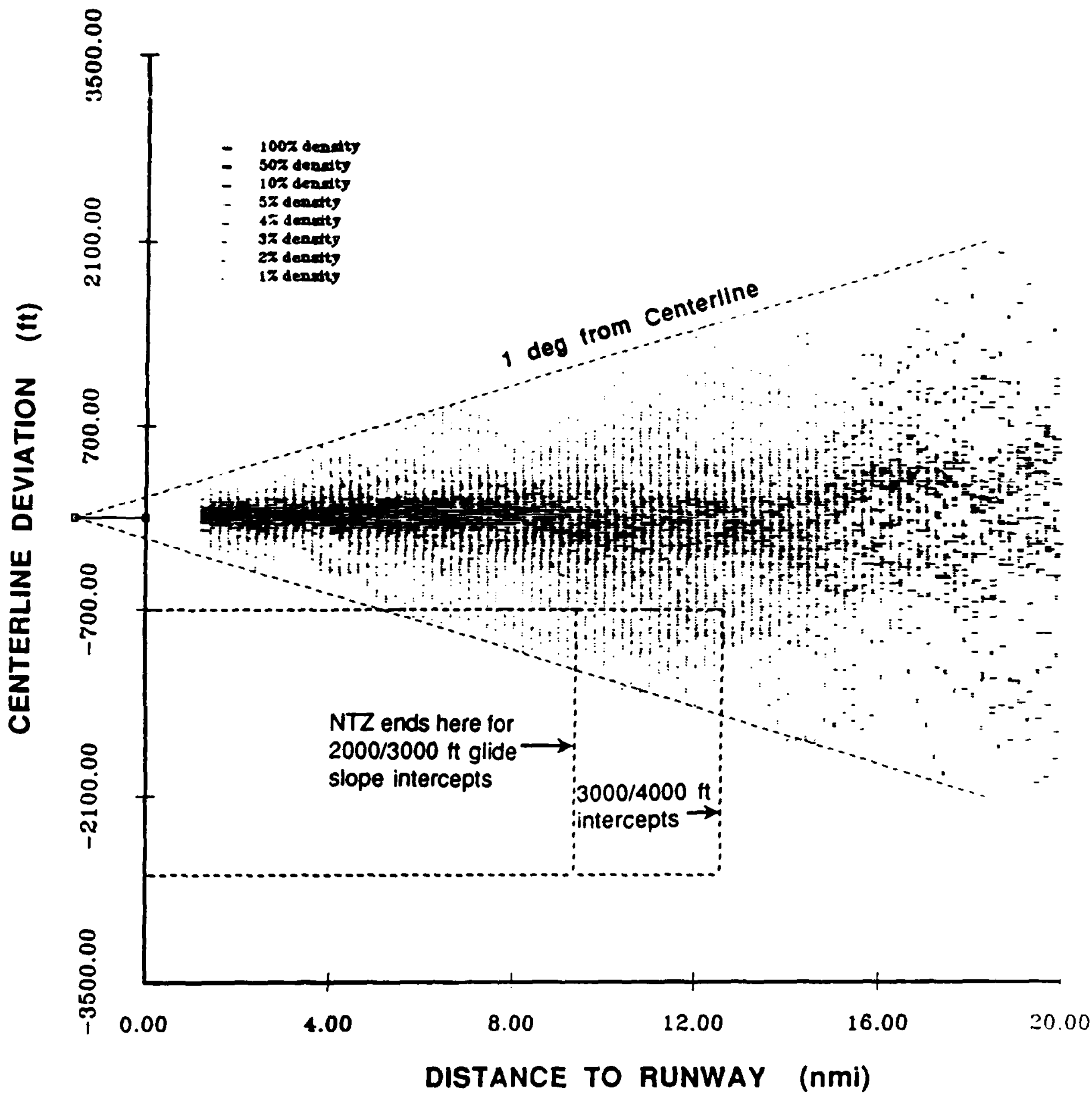

Figure 3-3. Aircraft position distribution of IFR approaches to Memphis 18R.

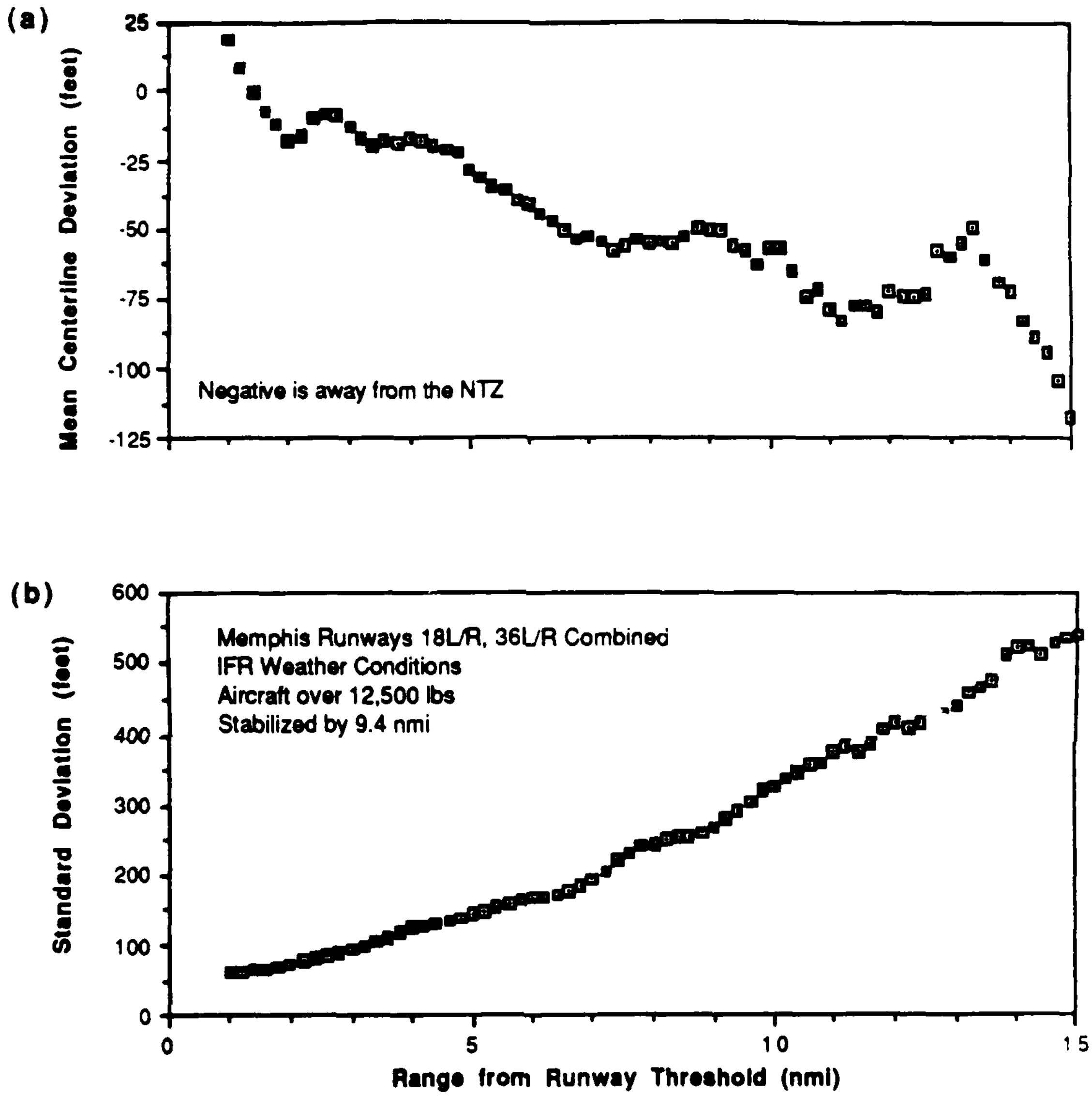

Figure 3-4. Statistics on Memphis localizer deviations. (a) Mean centerline deviation and (b) standard deviations. The number of arrivals was approximately 1,000 from 1 to 10 nmi and decreased from 1,000 to 300 by 15 nmi.

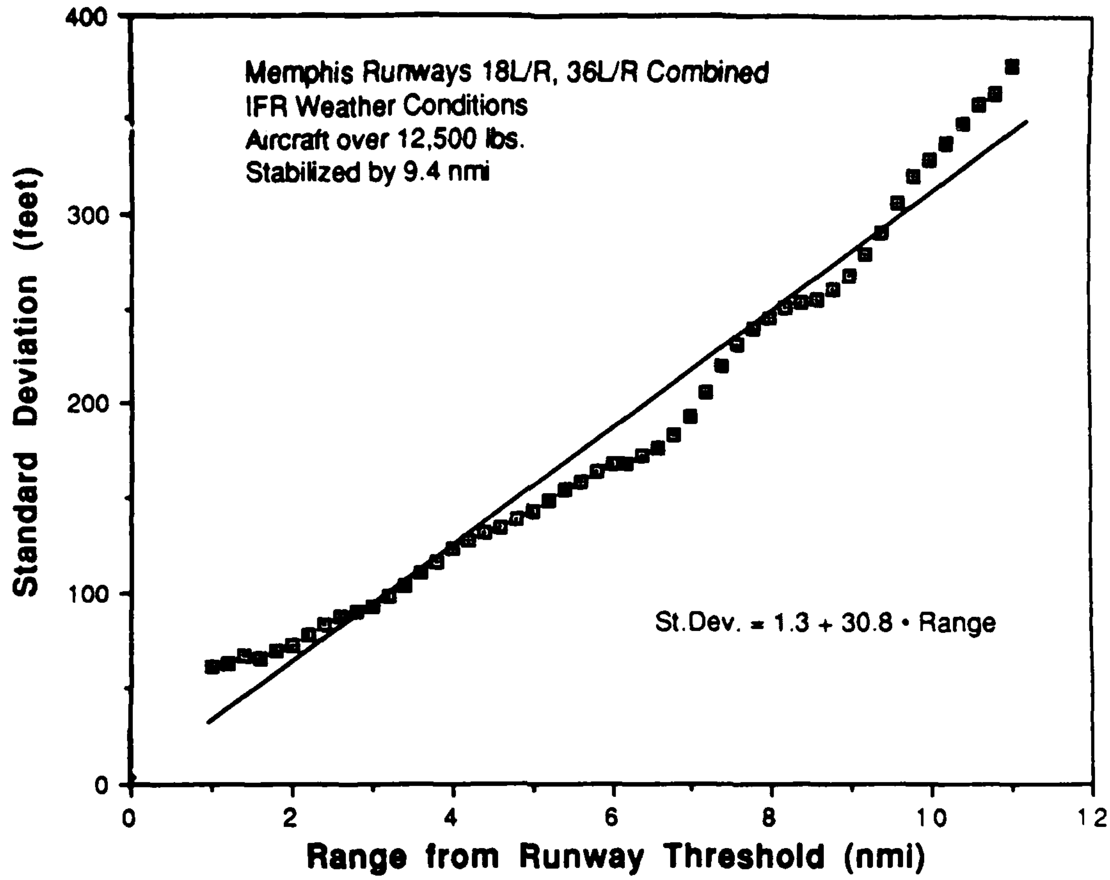

Figure 3-5. Statistics on the normal Memphis approach data that are included in the Collision Risk Model.

A third way to look at the FTE is to examine distributions at selected ranges. Figures 3-6(a) through 3-6(d) show four sections through a combined deviation distribution similar to the one in Figure 3-3. The sections are taken at ranges of 2, 5, 10 and 15 nmi from the runway threshold. These values correspond to ranges used in the risk model and used to create the simulation for the controller response experiments.

The fourth plot, Figure 3-7, shows the percentage of aircraft that would exceed a given distance away from centerline toward the adjacent parallel at each of the four ranges because of FTE. The figure is useful in estimating the difficulty of keeping aircraft out of an NTZ at various runway spacings. Consider the Memphis case as an example -- a runway spacing of 3,400 ft with the NTZ beginning at 9.4 nmi. The triangle (which is circled in the figure) indicates that about 4% of the aircraft could be expected within the lateral limits of the NTZ at 10 nmi, just before the NTZ begins. For simultaneous independent approaches, neither the deviating aircraft nor the one on the adjacent course can be allowed to descend until the deviation is corrected. This is probably manageable at the four percent level. But if the data are extrapolated to a 3,000-ft spacing, a less manageable 10% will be within the NTZ as it begins. Further discussion of the implications of the data is in Section 3.4.

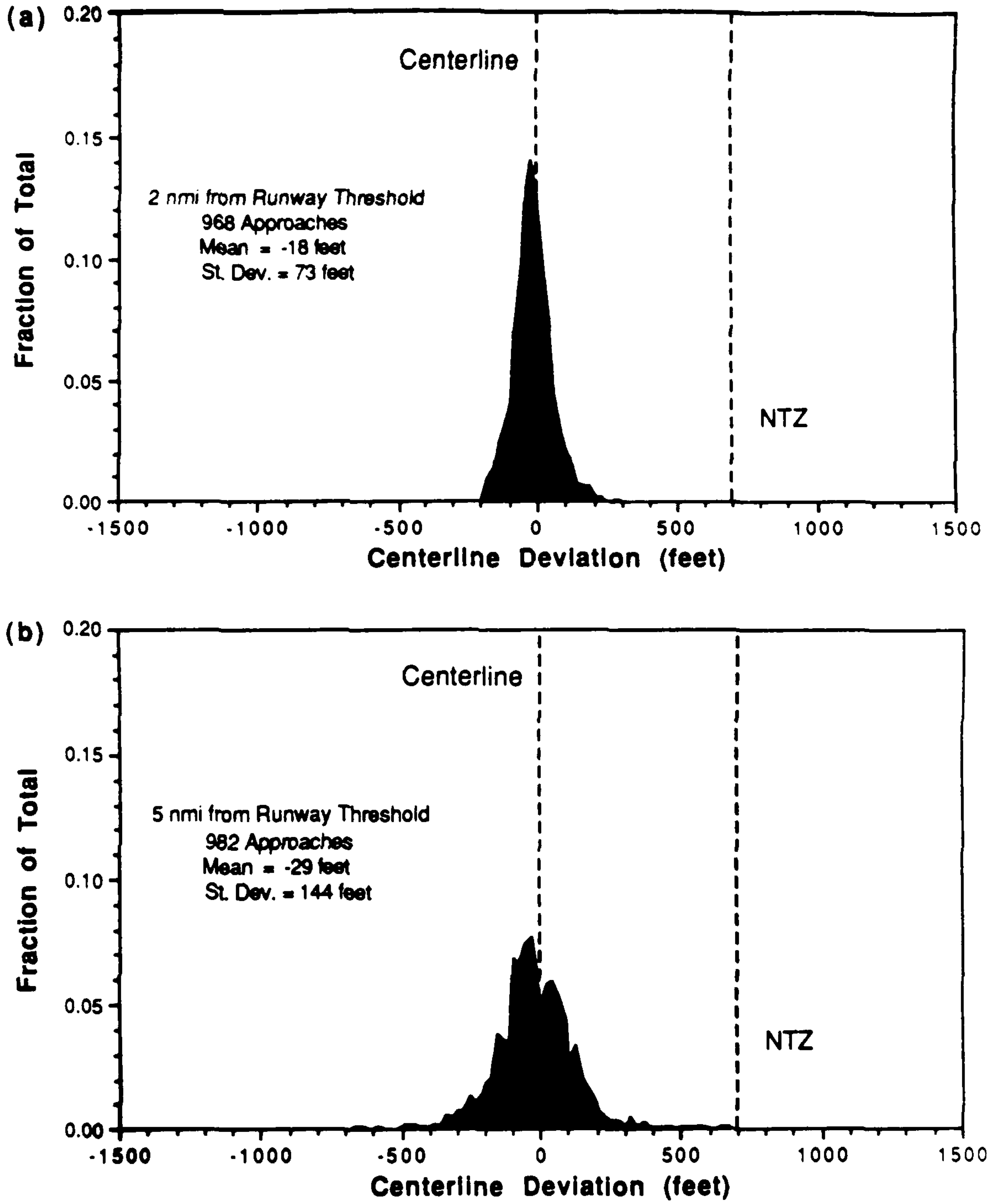

Figure 3-6. (a) and (b). The Memphis approach data distributions about the extended runway centerline at (a) 2 nmi and (b) 5 nmi. The data from the Memphis runways 18L/R, 36L/R were combined.

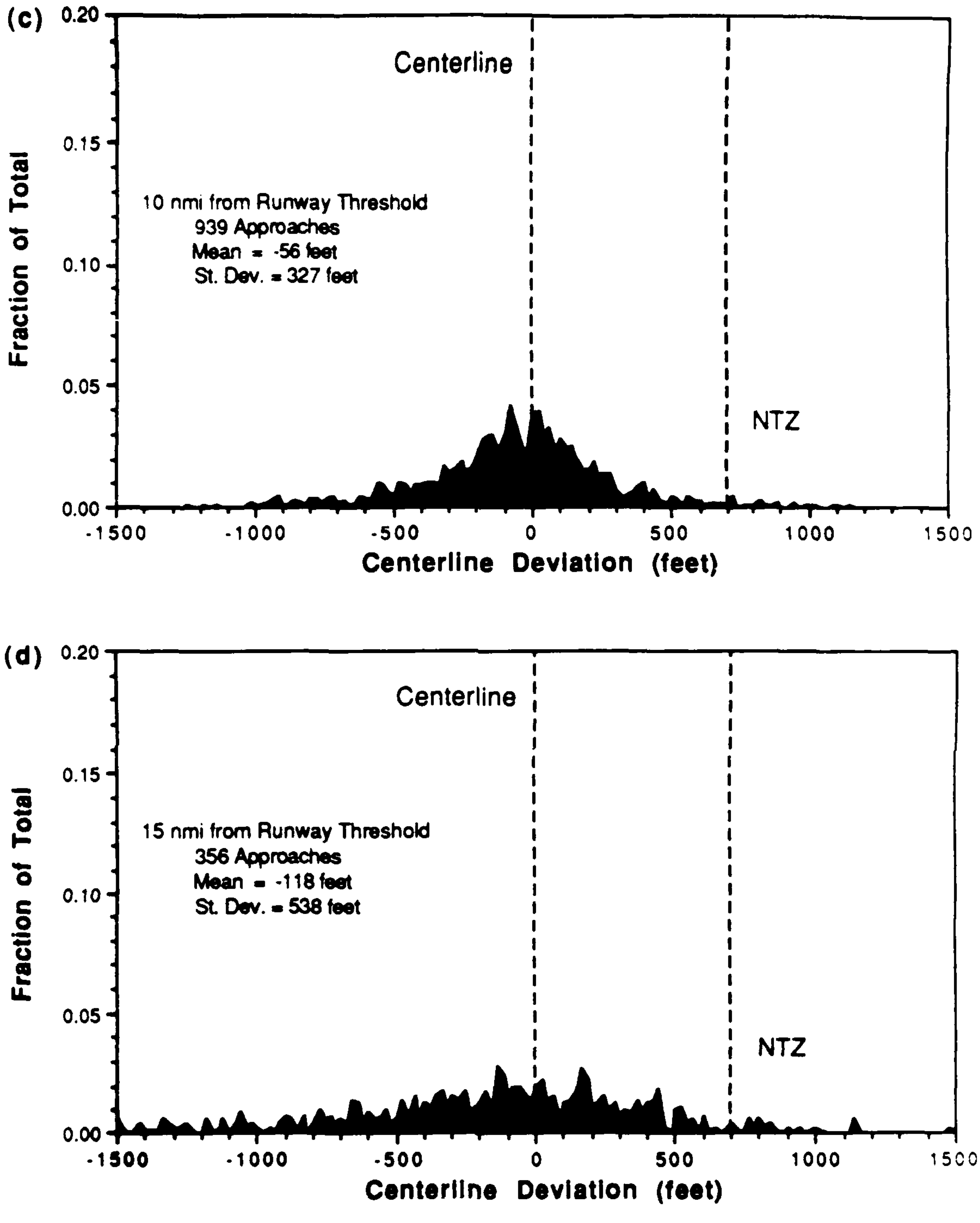

Figure 3-6. (c) and (d). The Memphis approach data distributions about the extended runway centerline at (c) 10 nmi and (d) 15 nmi. The data from Memphis runways 18L/R, 36L/R were combined.

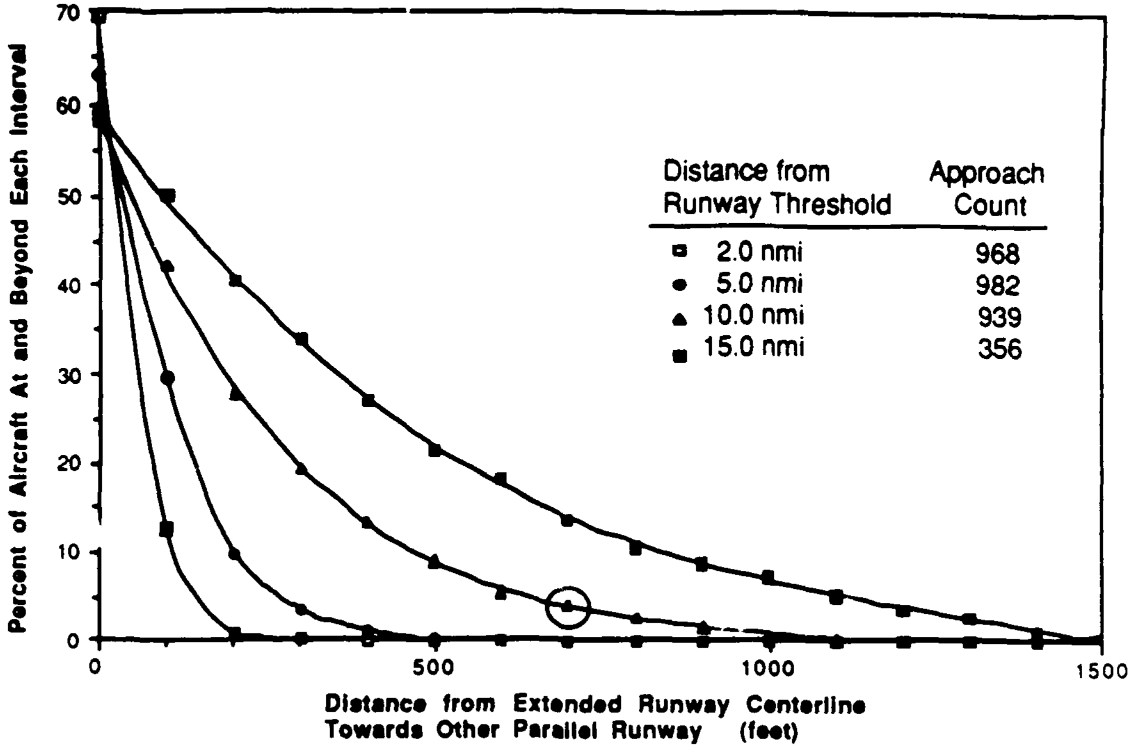

Figure 3-7. Memphis approach data at and exceeding each lateral 100-ft interval from the extended runway centerline towards the other parallel runway.

3.2.2 Chicago

The Chicago O'Hare data utilized in this report consist of large air transports defined as stabilized on the approach by 10.5 nmi from the runway thresholds. Over 95% of the data were recorded in IMC. The data from ten parallel approach courses are combined so that a positive deviation is toward the NTZ. The Chicago data set conditions are considered similar enough to the Memphis conditions for a satisfactory comparison, and the Chicago data are presented in Figures 3-8 through 3-10 in a similar format to the Memphis data.

The distribution of the Chicago independent arrival centerline deviations is shown in Figures 3-8(a) through 3-8(c) for the ranges 2.1, 5.1, and 10.2 nmi with 0.15-nmi range interval widths. There were not sufficient data for a similar analysis near 15 nmi.

The mean and standard deviations of the Chicago data for each range interval (0.15 nmi) are shown in Figure 3-9. The mean centerline deviation is generally away from the NTZ with an average value of about -15 ft. This differs from the Memphis data where the mean centerline deviation is away from the NTZ by an amount that increases with range.

The Memphis and Chicago standard deviations for the mean centerline deviations are shown together in Figure 3-10. The Memphis approaches have greater deviations up until about 4.6 nmi from the runway threshold. From 4.6 nmi, near the outer marker, to the runway threshold, the Memphis and Chicago arrivals behave very similarly.

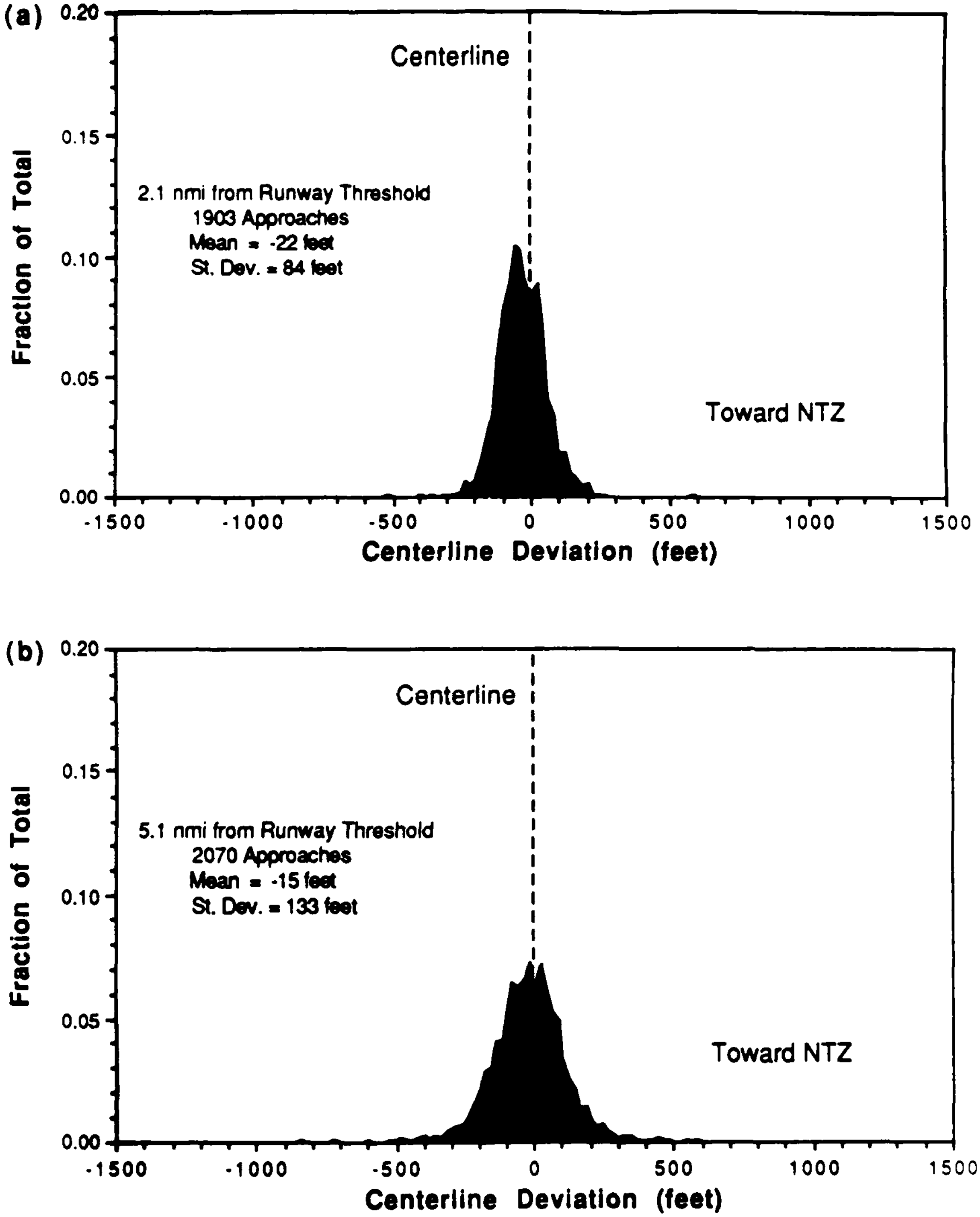

Figure 3-8. (a) and (b). Chicago O'Hare approach data distributions about the extended runway centerline at (a) 2.1 nmi and (b) 5.1 nmi. The data from O'Hare parallel runways were combined.

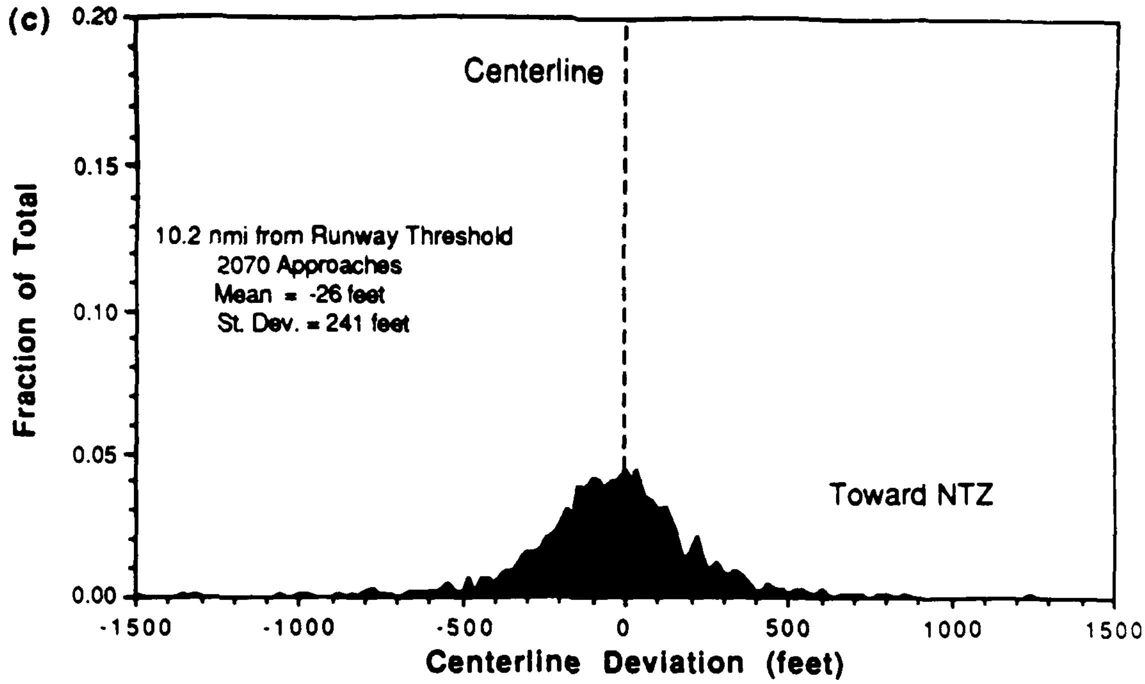

Figure 3-8. (c). Chicago O'Hare approach data distributions about the extended runway centerline at (c) 10.2 nmi. The data from O'Hare parallel runways were combined.

The difference in the centerline deviations between the two airports may be attributed to dependent versus independent arrivals. There may be other influences also, notably a difference in the localizer course angular widths. The Memphis localizer beams had an average of 4.15 deg course width during the data collection. Chicago O'Hare has an average of 3.72 deg weighted for the number of arrivals to ten different runways. The average Chicago localizer course width is 90% of the average Memphis course width. When the slopes of the standard deviations versus range are compared beyond 4.6 nmi, the slope of the Chicago data is 63% of that of the Memphis data. In addition, when Memphis tracks are filtered using the same algorithm as was used in the analysis of Chicago FTE data, the FTE standard deviations are consistent with the localizer course widths to within 1%, supporting localizer course width as the major source of the observed differences.

3.3 Autopilot Effect on FTE

FTE data from autopilot coupled approaches were examined to discover any differences between autopilot and hand flown approaches. It was supposed that autopilots might reduce FTE, and thus facilitate independent approaches to closely spaced parallel runways. An experiment to test this hypothesis was performed in Memphis with the cooperation of Federal Express [8]. The results of the Memphis experiment did not show a distinct difference between the two approach modes. The study used B727 and DC10 aircraft. Boeing Company data on the performance of newer autopilots were also examined. The newer autopilots show significantly smaller deviations than the hand-flown approaches measured at Memphis.

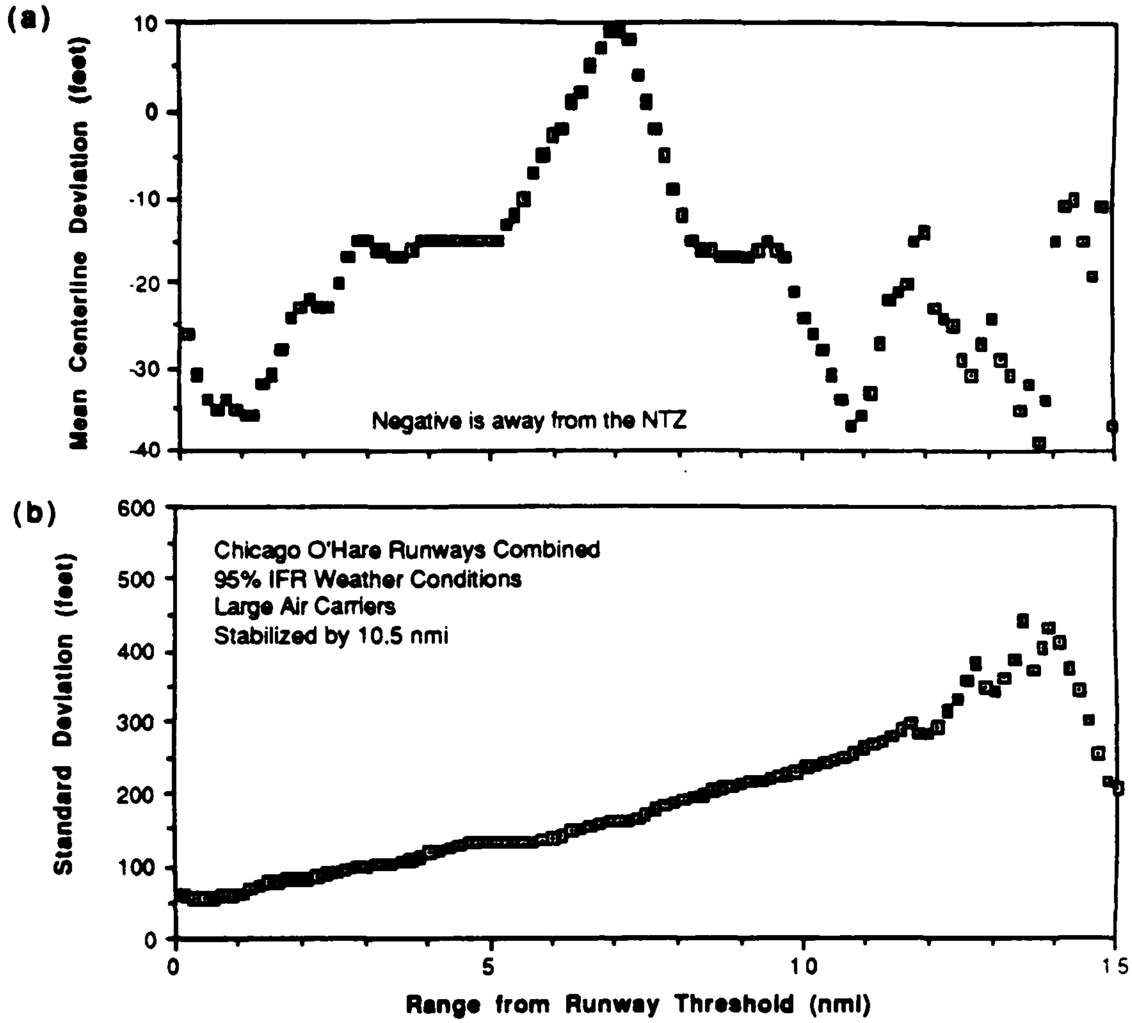

Figure 3-9. Statistics on Chicago O'Hare localizer deviations. (a) Mean centerline deviation and (b) standard deviations. The number of arrivals was over 2,000 from 0 to 10.5 nmi and decreased to near 0 at 15 nmi.

3.3.1 Memphis Experiment

An experiment to compare autopilot-coupled versus hand-flown approaches was carried out during normal Federal Express operations at Memphis. Data were gathered during four consecutive late night arrival periods on 30 May - 2 June 1989. Visual meteorological conditions prevailed all four nights with light winds, and the airport was operating under visual flight rules (VFR). Pilots were selected alternately to fly the approach manually without outside visual reference, or using the autopilot.

The approach data were processed using the same methods as the other Memphis site radar data, described in Section 3.2. The data for the experiment were grouped by runway. Figure 3-11 shows data collected from runway 18L. The hand-flown arrivals are compared to the autopilot-coupled arrivals and the dotted lines show the lateral deviation within which 90% of the aircraft were tracked. These results are typical.

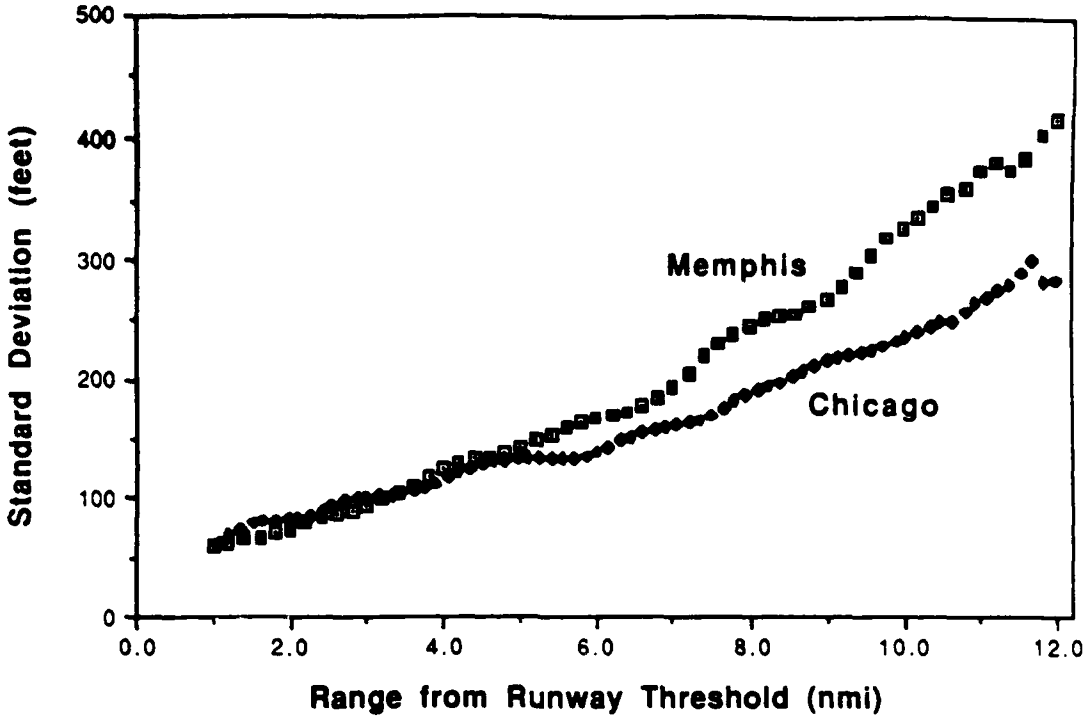

Figure 3-10. Memphis and Chicago O'Hare final approach standard deviations from the mean centerline deviations.

The difference in proportion of the number of aircraft that crossed into the NTZ after stabilizing on the localizer was examined in an effort to quantify differences between flight technical error in the two ILS approach modes. In combined data from *all* runways, six out of 89 hand-flown final approaches entered the NTZ within the stabilized flight segment while 11 out of 102 autopilot-coupled approaches entered the NTZ. A statistical comparison of the available data shows that there was no significant difference in flight technical error between the hand-flown and autopilot-coupled ILS approaches measured in the study.

3.3.2 Boeing Data

Data provided by the Boeing Company were examined to gain an understanding of the performance of the more advanced autopilots available in newer aircraft [9]. The data consisted of the maximum lateral deviations relative to the extended runway centerline of B747-400 aircraft during ILS approaches. The data also represent the localizer tracking performance for the B757 and B767 aircraft.

The following conclusions may be drawn from the Boeing data. The maximum centerline deviation for each approach was highly dependent on the localizer intercept angle and the distance from the centerline where the turn to final approach was started. Almost all of the simulated approaches remained within 600 ft of the extended runway centerline after they were considered "established" on the localizer according to the criteria described in Section 3.2. One nmi past stabilization all but four of the 668 simulated approaches remained within 200 ft of the extended runway centerline. The advanced autopilot tracking performance was much better than that observed in the Memphis experiment [8]. The Boeing data suggest that more advanced autopilots can provide significant reductions in FTE.

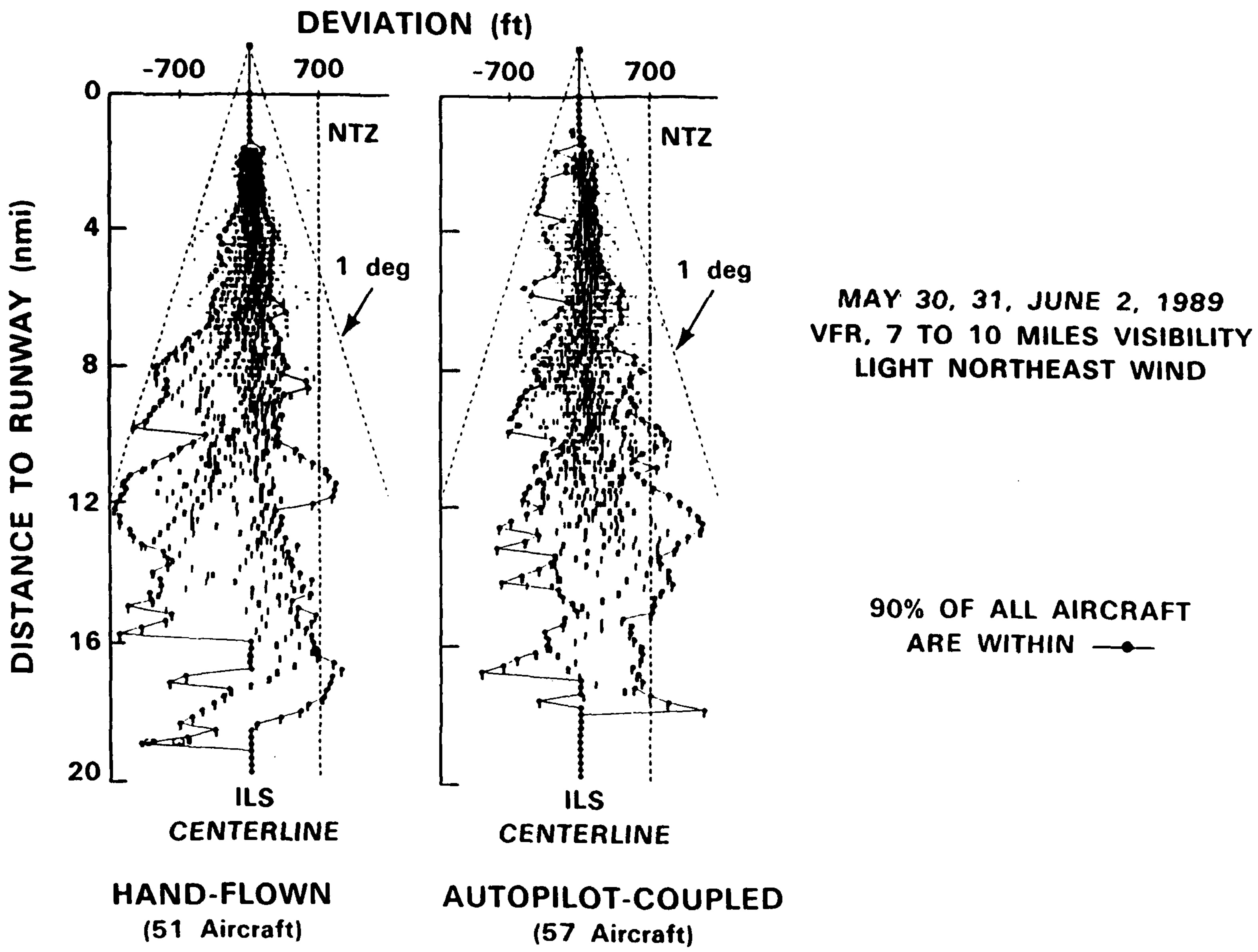

Figure 3-11. Aircraft position distributions on final approach to Memphis 18L contrasting hand-flown approaches to autopilot-coupled approaches.

3.4 Limitations Due to FTE

3.4.1 Monitoring Zone Maximum Range

Analysis of final approach FTE shows a conflict between the monitoring zone definition and the normal ILS approaches. The monitoring zone between parallel runways begins where aircraft begin to lose altitude separation during final approach. At Memphis International Airport, that distance is about 9.4 nmi from the runway threshold for 2,000-ft and 3,000-ft localizer intercept altitudes. Memphis has 3,400-ft runway separations and therefore 700-ft normal operating zones. Using 700 ft, Figure 3-7 shows that at 10 nmi, 4.1% of the aircraft that are stabilized on the localizer beam are within the NTZ.

As another example, if the approaches were conducted with 4,000-and 3,000-ft intercept altitudes, the monitoring zone would begin about 12.5 nmi from the runway. For this case, Figure 3-7 shows that 10% of the stabilized approaches would have penetrated further than 700 ft from the center line. If simultaneous arrivals were to be conducted at Memphis, controllers would have to intervene even more often to avoid NTZ penetrations. This would detract from the benefits gained by the independent arrivals. The following section addresses possible solutions to this conflict.

3.4.2 NTZ Penetration Reduction Measures

A number of suggestions have been made concerning technical improvements or modifications to existing ILS approach systems that may reduce the likelihood of penetration into the NTZ due to normal FTE, or ensure altitude separation at distances from the runway threshold where NTZ penetration is a problem. In cases where simultaneous ILS approaches are impractical because of a large unnecessary breakout rate caused by NTZ penetration, implementation of one or a combination of these changes may decrease the rate enough to allow simultaneous approaches to be used.

Additional study is needed to evaluate the potential of each of the changes for decreasing NTZ penetrations, or making the penetration unimportant by maintaining altitude separation during part of the ILS approach. An overview of the changes that have been suggested to date, along with a preliminary look at the advantages and disadvantages of each, is presented in the remainder of this section.

3.4.2.1 Microwave Landing System

The Microwave Landing System (MLS) promises to provide precision approach guidance using curved or segmented approaches. At longer ranges, the approach could be angled so as to avoid the NTZ. Details of how this might be implemented have yet to be worked out, and testing is needed to understand what kind of problems may be encountered with this type of approach to closely spaced parallel runways. Still, there is reason to believe that this may eventually become the preferred solution.

The major drawback to using the MLS system to reduce NTZ penetrations is the fact that neither the airports in question, nor most aircraft, are currently equipped with MLS. Therefore, a completely new precision approach system would have to be installed, with the associated cost and delay. A solution that can be implemented with the existing ILS equipment is preferred for the near future.

3.4.2.2 Runway Threshold Offset

Use of offset runway thresholds provides altitude separation between aircraft on the glideslope during ILS approaches. Since it is generally agreed that a 1,000-ft altitude separation is required for safety, and since the altitude separation provided is just over 300 ft per nautical mile of threshold offset for a three-degree glideslope angle, it would require threshold offsets of over three nautical miles to provide a 1,000-ft altitude separation between the two ILS glideslopes.

Runway thresholds at existing airports do not have anywhere near three nmi of offset, and the required extra real estate would make such large threshold offsets impractical at most airports where new runways are being constructed. Therefore, runway threshold offsets alone do not seem likely to provide an acceptable answer, but they could be part of a solution for the FTE problem.

3.4.2.3 ILS Localizer Offset

It would be possible to provide an angular offset to the localizer, so that the localizer centerline makes an angle of about one degree with the runway. The FTE data reported earlier indicate that a one-degree offset would be sufficient to eliminate NTZ penetrations due to normal FTE.

Unfortunately such a localizer angle offset would probably require the physical repositioning of the ILS localizer transmitter antenna. It would also be impossible to carry out category II and category III ILS approaches using an ILS that has been modified in this way.

3.4.2.4 ILS Glideslope Angle Offset

Altitude separation between aircraft on the ILS glideslope can also be provided by changing the glideslope angle. If the glideslope angle for one of the parallel approaches is raised by one degree (for example a three-degree angle for one glideslope and a four-degree angle for the other), then for distances larger than ten nautical miles from the runway threshold, a minimum of 1,000 ft of vertical separation is provided between the glideslopes, assuming no runway threshold offset.

For airports where a one-degree difference between the glideslopes can be provided without having the glideslope become too steep, this option may provide a relatively simple answer. A slight modification to the existing PRM alert code could be implemented to generate an alert only if an NTZ penetration is predicted, and the aircraft are not separated by at least 1,000 ft vertically.

3.4.2.5 ILS Localizer Narrowing

Currently, the standard width of the ILS localizer course, measured at the runway threshold, is between 400 and 700 ft. In practice, the course width is set to 700 ft at the threshold. Assuming that the major contributor to FTE is the width of the localizer at long ranges, if the localizer width is decreased, the FTE should decrease proportionally. Therefore, the distance from the threshold at which NTZ penetrations due to FTE become a problem will increase, and the NTZ penetration problem may be solved.

There are two issues here. First, it is not currently known whether limitations on the precision with which the ILS localizer is flown are due to the width of the localizer course or the capability of the pilot or autopilot to control the aircraft. Measurements are

currently underway at Memphis, where the ILS localizer to 18L/36R has been narrowed from 700 ft at the runway threshold to 486 ft for 18L and 492 ft for 36R, giving a three-degree course width. The results of comparing approaches flown on 18L/36R with narrowed localizers to approaches flown on 18R/36L with normal width localizers will aid in understanding the potential of localizer narrowing for reducing FTE-induced NTZ penetrations.

Second, autopilot systems that are capable of autoland are calibrated to expect a 700-ft course width at the runway threshold. Therefore, this modification would render the runways unsuitable for Category II or Category III ILS approaches.

3.4.2.6 Air Traffic Controller Intervention

NTZ penetrations may also be eliminated if the appropriate approach controllers provide corrective vectors to off course aircraft prior to the handoff to the tower controller and before the start of the monitoring zone. This would be practical if the workload and intervention rate is small.

3.4.2.7 Autopilots

It has been suggested that it be made a requirement that all simultaneous ILS approaches to closely spaced runways be flown coupled to the autopilot. Measurements made to date indicate that the older autopilots predominantly in use in the aging aircraft flying today do not provide significant FTE reductions. The new autopilots being manufactured today are considerably more advanced, and for aircraft equipped with them, FTE could be reduced if the flight crew used them during simultaneous ILS operations.

3.4.2.8 Lesser Intercept Angles

A portion of the FTE measured at Chicago and Memphis is actually due to delayed stabilization on the localizer course. If an aircraft approaches the course at a large angle, the pilot has more difficulty aligning the aircraft on the course, and may oscillate across it once or twice before stabilizing. Current procedures require the final controller to assign an intercept heading no greater than 30 degrees. If the heading were reduced to 20 degrees, the aircraft could stabilize more quickly and reduce FTE near the localizer intercept point.

4. CONTROLLER/RADAR

Highlights

- **Controllers break out the endangered aircraft before the blunderer penetrates the NTZ (3,400-ft runways monitored by PRM at a 2.4-second, or shorter, update interval).**
- **More frequent radar updates give earlier warning to the endangered aircraft. For a 3,400-ft spacing, 30-deg blunder, the controller broke out the endangered aircraft 2.5 seconds before NTZ penetration by the blunderer for a 1-second update interval, 1.4 seconds before penetration for a 2.4-second update interval, and 2.5 seconds after penetration for a 4.8-second update interval.**
- **Controllers had a negligible rate of unnecessary breakouts for typical flight path variations.**
- **Controllers are unanimous in their enthusiasm for the PRM system, and virtually all believe it could be used for safe monitoring at 3,400 ft.**
- **Current ATC procedures are expected to be adequate for closely spaced runways monitored by the PRM system, with the exception of a change in breakout phraseology.**

Chapter 2 described performance of the Precision Runway Monitor radar and displays. Chapter 3 described how aircraft fly on a normal approach, thereby setting up the conditions under which aircraft are monitored, and the initial conditions of the aircraft before a blunder occurs. This chapter describes the performance of the controller and the radar as a system, as they work together to monitor aircraft on approach, and to issue blunder resolution instructions to pilots.

Studies of air traffic controller interaction with the PRM were conducted at both Memphis and Raleigh. The testing consisted of the presentation of simulated approach blunders to the controllers, and measurement of their reaction time in breaking out endangered aircraft when an approach blunder was committed by an aircraft on the adjacent parallel approach. The rate at which controllers directed unnecessary breakouts was also studied, and controller opinions about PRM were surveyed.

4.1 Experimental Design

4.1.1 Controller Participation

The testing was conducted in 1990 from January to July. Twenty-five pairs of controllers participated at each site, one pair for each week during the simulation. Half of the pairs were employed at the local facility, while others visited from other facilities across the country. The visiting controllers were selected for direct experience in independent

parallel approach monitoring at 4,300 ft or greater. With one exception, controllers who participated at one site did not participate at the other.

Monday of each week was devoted to familiarization with the PRM program, operation of the monitor display, and simultaneous parallel approach procedures. Controller response data were collected from Tuesday through Thursday in eighteen simulation sessions at Memphis and nine simulation sessions at Raleigh. Each session lasted about one hour. Debriefing and completion of the controller survey occurred on Friday.

4.1.2 Monitoring Sessions

Every effort was made to create as realistic a simulation as possible. The density of traffic, types of aircraft represented, altitudes, speeds, and headings, were based on traffic information from the Raleigh and Memphis tower staffs, and recorded arrival traffic at Memphis. Each simulation depicted the parallel runways of the facility conducting the test.

The sessions depicted a heavy arrival period at the airport, with aircraft arriving at near the maximum rate for independent parallel approaches in IMC. At variable intervals, one of the aircraft would blunder so that another was endangered. Blunders occur so infrequently in real situations that a realistic simulation would not have portrayed any blunders over a three day period. Instead, 3-4 blunders were staged per hour. Controllers were clearly aware that blunders would occur, but between the blunders injected at varying intervals, there were enough normal approaches intermixed so that controllers could not identify the blundering aircraft in advance. Test sequences were varied each week, so that one pair of controllers could not determine where the blunders would occur if they spoke to previous participants.

4.1.3 Control Room Environment

In the planned PRM implementation, the PRM displays would be in the TRACON control room, near the other radar controllers managing traffic in the terminal area. During the simulation, the controllers were seated in a room containing only the equipment necessary for parallel approach monitoring. The more sterile environment, while lacking realism from distractions, insured that the simulation would not interfere with ongoing TRACON operations, and allowed better control of the experiment.

At some facilities, today's monitor controllers are responsible for monitoring longitudinal spacing between aircraft on the same runway. The approach controllers set up the spacing, but the monitor can intervene to correct it if the required spacing is likely to be lost. At Memphis, an occasional need to make this intervention was presented to the monitor controller.

4.1.4 Data Collection

All track data were recorded on digital tape for later analysis. The audible caution alert from the blunder predictor, the controller's instructions to pilots, and the pilot responses were recorded on audio tape, along with a time code that provides synchronization to the digital tape.

At Raleigh, technical and operational difficulties associated with the greater complexity of coordinating remotely located flight simulators, and of sharing the portions of the PRM system used for the simulation with developmental tests on the radar itself, prevented recovery of all of the data recorded from the simulations. The effect of this was

a reduction in the number of observations of each scenario at the update intervals under analysis. In addition, limitations in the speed of the computer used in the demonstration system prevented a clean measurement of the advantages of the 0.5-second update interval. Although the radar interrogated the aircraft every 0.5 seconds, processing delayed the display update by as much as 1.5 seconds after the reply was received from the aircraft, and for some runs the display update was made only for every other radar update. For these reasons, data from the two sites are treated separately.

4.1.5 Independent Variables

In each of the monitoring sessions, there were a number of independent variables which it was believed might affect the controller responses. The variables were:

(a) Sensor update interval: The primary variable, sensor update interval would differentiate between the PRM alternatives, and combined with accuracy, differentiate the PRM from older sensors. At both sites sensor update intervals of 1.0, 2.4, and 4.8 seconds were tested, with 0.5 seconds added at Raleigh. A 4.8-second interval was of interest because monopulse sensors, planned to replace existing beacon sensors around the world, will rotate with this period and provide the same one-milliradian accuracy as the PRM. Although the back-to-back radar at Memphis was limited to a 2.4-second interval, the simulation did not require the radar itself, and the displays were not interval limited. Live flights were monitored at a 2.4-second interval at Memphis, and a 0.5-second interval at Raleigh.

(b) Runway separation: This is the second most important variable examined during the experiments. A major finding of the report was expected to center on PRM applicability at runway spacings near Raleigh's 3,500 ft and Memphis' 3,400 ft. However, in order to examine the effect at different spacings, a 3,000-ft simulation (at Raleigh) and a 4,300-ft simulation (at Memphis) were conducted near the end of the 25 weeks to replace the 3,400-ft, 4.8-second update interval scenarios on which sufficient data had already been collected.

(c) Blunder angle: Blunders were staged using the worst case scenario, where an aircraft rolls smoothly into a standard rate turn and holds the bank until a 30-degree heading change toward the adjacent approach course is achieved. Blunders having a 15 degree heading change were also staged to measure the system performance for less severe blunders.

(d) Blunder range from runway threshold: Blunders were staged both outside and inside the outer marker, and after the missed approach point. The difference is important because of the contribution of FTE to the blunder starting conditions, and the relative stability of the aircraft at the various spacings. In addition, when flight simulators or real aircraft are used, pilot response time is assumed to be different when the aircraft is nearly ready to land at low altitudes.

(e) Turbulence: Simulation scenarios modeled both calm conditions and more turbulent conditions which increase the amount of FTE during the ILS approach. It was suspected that controllers might become

desensitized, because the beginning of a blunder could appear as a response to the increased FTE.

(f) Speed: Most blunders were staged with both aircraft operating at speeds typical of transport jets. But in one scenario, the endangered aircraft was slower.

(g) Distractions: Memphis included a blunder scenario where one aircraft had an erratic flight path (one that is not due to turbulence but presumably due to the behavior of the pilot or aircraft), but did not enter the NTZ. Then an aircraft on the adjacent approach path deviated and penetrated the NTZ.

(h) Controller experience level: Approximately half of the controllers who participated in the study were experienced monitor controllers and half were controllers who had no previous experience as monitor controllers. This permitted an analysis based on controller experience level.

4.1.6 Unique Features of the Raleigh Simulation

Aircraft tracks were generated with combinations of computers and flight simulators located in Dallas and Oklahoma City. The use of flight simulators had the benefit of exploring the interaction between controllers and flight crews and obtaining flight crew response data. The computer, or Desk Top Simulator (DTS), was designed to generate up to 200 preprogrammed tracks of aircraft arriving at Raleigh. The DTS generated all tracks for the blundering aircraft. Flight simulator tracks were obtained from either an MD80 flight simulator operated by American Airlines in Dallas, or an FAA B727 flight simulator located at the FAA Academy in Oklahoma City. The flight simulators were used to represent the endangered aircraft. Scheduling conflicts limited the flight simulators to about one third of the sessions. A DTS was used to represent the endangered aircraft for the rest of the sessions.

Session execution was controlled by the test director, DTS operator, and pseudopilot. The test director exercised overall control and coordination of each mission. Aside from the preprogrammed tracks, the DTS operator could generate a spontaneous track for display. A live pseudopilot made the voice check-in for both DTS and flight simulator tracks. The audible caution alert generated from the blunder predictor was a continuous tone, which lasted as long as the alert condition persisted.

4.1.7 Unique Features of the Memphis Simulation

All of the data and most of the audio presented to the controller was prepared in advance. Computer simulated tracks were modeled on data recorded during dependent parallel approaches at Memphis. Only one variable was changed at a time, so the effect of that variable could be studied in isolation.

An audio playback unit provided prerecorded background audio which the subjects heard during each simulation session. Each subject was responsible for monitoring one runway, and heard standard communications between the local controller and pilots assigned to that runway. Two pseudopilots acknowledged controller communications requesting speed adjustments and breakouts and provided inputs that caused the simulated aircraft to comply with controller instructions. The audible caution alert generated from the blunder predictor was generated by a DECtalk speech synthesizer.

Presentation of the simulation was monitored by the simulation coordinator. The test conductor was with the subjects in the subject participation room. The test conductor insured that all test procedures were properly followed and recorded any significant interactions between the controllers or anomalies in the simulation that could affect the interpretation of the data collected. The test conductor was able to switch between listening to the subjects, the pseudopilots, and the background audio.

4.2 Analysis of Data

4.2.1 Controller Blunder Response Time

Before acting to resolve a blunder, the controller pair monitoring the two approaches must first decide that a blunder is occurring. Then, if the blundering aircraft cannot be returned to course, the monitor controllers must transmit a breakout instruction to the endangered aircraft. The sooner the instruction is transmitted, the more time is available to maneuver the endangered aircraft out of the way. Thus, the controller response time is a critical element in a successful blunder resolution. Procedure sets limits on the controller response. Safe separation is lost whenever an aircraft enters the no transgression zone (NTZ), and the controller must take action, usually to break out the endangered aircraft. The controller may direct the breakout earlier if he believes that the situation requires it.

Compared with existing systems, the PRM changes the radar update interval and accuracy, adds color to the display, and displays a ten-second track projection. The PRM also alerts the controller of a possible blunder by changing the color of the suspected aircraft from green to yellow, and by sounding an audible alert, whenever the aircraft is projected to enter the NTZ within 10 seconds. These features are inextricably linked with the response time of the controller. The controller response without them was not measured.

Figure 2-1 diagrams the events occurring during a blunder resolution. One measure of the effectiveness of the system is the "alert response time." Measurement of this time begins when the audible alert sounds and ends when the controller begins to speak the breakout instruction.

Because the audible alert can only sound when the target display is updated (at whatever update interval is being tested), the "alert response time," taken on its own, tends to ignore some of the advantage of the higher update rate. It is therefore not useful as a single measure of the controller/radar effectiveness. A better measure is how much in advance of the blundering aircraft's penetration of the NTZ the controller began speaking. This was termed, "net controller lead time." This measures the combined effects of (1) the update interval, (2) the performance of the alerting algorithm, and (3) the interaction of the controller with the alert. Alert response time and net controller lead time are illustrated in Figure 2-1.

4.2.1.1 Alert Response Time

Alert response times, as diagrammed in Figure 2-1, were analyzed to understand differences which may be attributed to four variables: sensor update interval, angle of approach blunder, runway separation, and controller experience. The effect of changes in the value of each of these variables on measured response times is discussed in the remainder of this section.

4.2.1.1.1 Effect of Sensor Update Interval

Alert response time data are presented in Table 4-1 for the 1.0-and 2.4-second update intervals. The table includes all Memphis results from all scenarios combined presented with 3,400-ft spacing. There is little difference in alert response time due to update interval. This is confirmed by the Raleigh data presented in Section 4.2.1.1.2.

Table 4-1

A Comparison of Alert Response Times with 3,400-ft Runway Separation (Memphis Data)

Update Interval	1.0 s	2.4 s
Number of Responses	475	472
Maximum Response (s)	16.3	11.5
Minimum Response (s)	-2.6	-2.7
Standard Deviation (s)	2.3	2.0
Mean (s)	3.2	3.0

The results for the 4.8-second interval are presented separately in Table 4-2 because only controllers in the first 13 weeks viewed all three intervals at 3,400-ft runway spacing. The data were collected to assess the benefit if the new displays and one-milliradian radar accuracy were applied to 3,400-ft spacing without changing the update interval from that of the production Mode-S sensor. The mean alert response time for the approach blunders presented at 4.8-second interval was approximately one second slower than that seen with the other two sensor update intervals.

Table 4-2

A Comparison of Alert Response Times with 3,400-ft Runway Separation (Memphis Data, Weeks 1 - 13)

Update Intervals	1.0 s	2.4 s	4.8 s
Number of Responses	255	256	198
Maximum Response (s)	15.1	9.1	12.2
Minimum Response (s)	-2.6	-2.6	-2.3
Standard Deviation (s)	2.4	2.0	2.3
Mean (s)	3.1	2.9	4.1

4.2.1.1.2 Effect of Blunder Angle

Table 4-3 shows the effect of blunder angle at the three sensor update intervals from the Memphis simulations. Data from all scenarios for a given angle and update interval are combined. Results indicate that at the shorter update intervals, the mean alert response times for 30-degree blunders are approximately 1 second faster than for 15-degree blunders. With a 30-degree blunder, penetration of the NTZ occurred more rapidly than with a 15-degree blunder. There was less time before NTZ penetration and so the controller reacted more rapidly.

Table 4-3

A Comparison of Alert Response Times for 15-degree versus 30-degree Blunders with Runway Separation of 3,400 ft
(Memphis Data)

Update Interval	1.0 s		2.4 s		4.8 s	
Angle	15 deg	30 deg	15 deg	30 deg	15 deg	30 deg
Number of Responses	198	198	198	196	100	98
Number of Controllers	40	40	40	40	26	26
Maximum Response (s)	10.0	7.0	11.5	7.4	10.8	12.2
Minimum Response (s)	-2.6	-2.4	-2.4	-2.7	-2.3	-2.3
Standard Deviation (s)	2.3	1.5	2.1	1.5	2.5	2.1
Mean (s)	3.4	2.5	3.4	2.5	4.0	4.2

Raleigh results presented in Table 4-4 support the finding that the mean alert responses are generally affected by the angle of the blunder. The results suggest that the response for a 30-degree blunder was faster than for a 15-degree blunder. This was true for all sensor update intervals. The mean values of alert response time measured at Raleigh and Memphis are not directly comparable, a finding which is discussed below in Section 4.2.1.3.

Table 4-4

A Comparison of Alert Response Times for 15-degree versus 30-degree Blunders with Runway Separation of 3,500 ft
(Raleigh Data)

Update Interval	0.5 s		1.0 s		2.4 s		4.8 s	
Angle	15 deg	30 deg	15 deg	30 deg	15 deg	30 deg	15 deg	30 deg
Number of Responses	5	40	8	10	10	47	6	32
Maximum Response (s)	8.8	8.6	16.0	8.2	11.8	9.3	14.1	11.0
Minimum Response (s)	0.2	-2.8	6.2	1.2	0.6	-0.8	6.6	-2.6
Standard Deviation (s)	3.5	2.5	2.3	1.5	3.4	2.2	2.5	3.3
Mean (s)	6.1	5.0	9.5	5.6	9.2	4.9	10.3	4.9

4.2.1.1.3 Effect of Runway Separation

Table 4-5 compares alert response times for two different runway separations in the Memphis simulation. Data assembled for the table combine all blunders at the 4.8-second sensor update. The mean is 2.4 seconds faster at the 4,300-ft spacing than at 3,400 feet.

Table 4-5

A Comparison of Alert Response Times for Approach Blunders Presented at 4.8-s Sensor Update Interval
(Memphis Data)

Runway Separation	3,400 ft	4,300 ft
Number of Subjects	26	14
Number of Responses	198	131
Maximum Response (s)	12.2	8.8
Minimum Response (s)	-2.3	-5.0
Standard Deviation (s)	2.3	3.0
Mean Response Time (s)	4.1	1.7

One possible explanation for the difference in mean alert response time due to the larger NOZ is that the controllers had the opportunity to observe the blundering aircraft for one or two more radar update intervals prior to NTZ penetration. When the caution alert sounded, the aircraft was far from the centerline, there was little likelihood that this was an FTE deviation, and the controller was ready to respond.

Table 4-6 breaks down the responses for 15-and 30-degree blunders. Here, the blunder angle does not seem to affect the 3,400-ft case, but at 4,300 ft, the controllers responded approximately one second quicker for the 15-degree blunders. This fits the previous theory: at 15 degrees, even more scans have convinced the controller that the aircraft is headed unalterably toward the NTZ.

Table 4-6

A Comparison of Alert Response Times from Approach Blunders Presented at 4.8-s Sensor Update Interval, with Deviation Angles of 15 degrees vs 30 degrees
(Memphis Data)

Runway Separation	3,400 ft		4,300 ft	
Angle of Deviation	15 deg	30 deg	15 deg	30 deg
Number of Responses	100	98	61	70
Maximum Response (s)	10.8	12.2	8.7	8.8
Minimum Response (s)	-2.3	-.6	-5.0	-4.2
Standard Deviation (s)	2.5	2.1	3.3	2.7
Mean Response Time (s)	4.0	4.2	1.1	2.2

4.2.1.1.4 Effect of Controller Experience

Table 4-7 shows the effect of monitor controller experience on alert response time. The novice group, while radar qualified, had no monitor controller experience prior to the simulation. In the experienced group the mean level of experience as a monitor controller was approximately 4 years. The range of experience was generally 2 to 5 years. However, one controller had 7 and another 12 years experience. The means indicate that the experienced monitor controllers responded approximately 0.8 seconds later than the

controllers who had no previous monitoring experience. One might expect the experienced monitor controllers to have reacted more quickly. However, it may be that the more experience one has in a situation, the higher the awareness of the many things to consider. It also may be that with experience, the controller has the confidence to let the situation develop further before it is necessary to intervene.

Table 4-7

A Comparison of Overall Alert Response Times of Experienced vs Novice Monitor Controllers
(Memphis Data)

Monitor Controller Experience	Novice	Experienced
Number of Controllers	14	14
Number of Responses	333	331
Standard Deviation (s)	2.0	2.2
Mean (s)	2.8	3.6

4.2.1.2 Net Controller Lead Time

Table 4-8 presents mean values of net controller lead time. The values are a measure of how much in advance of the blundering aircraft entering the NTZ the controller broke out the endangered aircraft. Given that the blundering aircraft went on to enter the NTZ and continued to endanger the other aircraft, increases in controller lead time translate directly to more time for the endangered aircraft to maneuver clear. The time is a reasonable measure of how much advance warning the system (radar, displays, predictors, controller training, and procedures) gives to the endangered aircraft. The faster updates give earlier warnings. Table 4-8 shows the mean values of all the times shown in Figure 2-1.

Table 4-8

Net Controller Response Lead Time
Mean Seconds Prior to NTZ Penetration at 3,400 ft
(Memphis Data)

Update Interval	1.0 s		2.4 s		4.8 s	
Blunder Angle	15 deg	30 deg	15 deg	30 deg	15 deg	30 deg
Caution Alert Lead Time (s)	7.4	5.0	6.2	3.9	4.2	1.7
Alert Response Time (s)	3.4	2.5	3.4	2.5	4.0	4.2
Net Lead Time (s)	4.0	2.5	2.8	1.4	-0.2	-2.5

4.2.1.3 Differences between Raleigh and Memphis Data

A comparison of the Memphis and Raleigh mean alert response times, Tables 4-3 and 4-4, indicates that for sensor update interval conditions tested at both sites, the mean alert response times obtained at each site were quite different. For example, Raleigh data

indicated mean alert response times for 1-second sensor update interval and 30 degree blunders to be approximately three seconds longer than those indicated by the Memphis data. At 2.4-second update, the difference is approximately 2.4 seconds.

Analysis has identified several factors which could account for the difference. First, different tracker gains were used at each site and surveillance noise was included at Memphis but not at Raleigh. The effect of these differences would have caused the caution alert to activate approximately one second earlier at Raleigh. This appears to account for part of the longer mean response time at that location.

In order to identify additional factors which may have contributed to the longer response times at Raleigh, a follow-up survey was disseminated to the 50 controllers who participated at each site. The survey was mailed to the controllers and results are being analyzed as they are received. At this time approximately 50% of the survey forms have been returned and analyzed. A look at this partial sample of responses indicates that two factors may have contributed to the longer response times at Raleigh.

First, subtle differences in the subject instructions used at each site may have resulted in controllers at Memphis making fuller use of the predictive caution alert. The majority of controllers at Raleigh reported that they usually waited until NTZ penetration had occurred before breaking out the endangered aircraft. They waited for the warning alert. This is consistent with current procedures for independent parallel approaches to runways separated by 4,300 ft or more. Conversely, the majority of controllers at Memphis reported that they usually did not wait until NTZ penetration occurred before breaking out the endangered aircraft. They usually broke out the endangered aircraft after the caution alert. It is evident that to obtain optimum response times during actual operations with closely spaced parallel runways, appropriate controller training and procedures, emphasizing the need to make use of the predictive capabilities of the PRM, are required.

Second, differences in the presentation of false breakout opportunities at each site may have encouraged controllers at Raleigh to take a "wait and see" attitude, resulting in longer alert response times. At Memphis there were two types of false breakout opportunities: inadvertent (caused by radar noise and FTE) and deliberate (where an aircraft previously stable on the approach course turns toward the NTZ and then, just before NTZ penetration, turns back to the approach course). At Raleigh, false breakout opportunities were all deliberate. Many of the deliberate false breakout opportunities were nearly indistinguishable from blunders. Controllers at Raleigh may have become conditioned to waiting for the deviating aircraft to return to course, resulting in longer response times.

The major reasons for the difference in response times between Raleigh and Memphis thus appear to be differences in training and differences in the tracks of non-blundering aircraft that cause caution alarms. Examination of final approach data collected at Memphis indicates that, while flight paths similar to the deliberate false breakout opportunities do occasionally occur, they are rare. They are also intermixed with more frequent caution alarms caused by a combination of radar noise and FTE. Therefore, with respect to the tracks of non-blundering aircraft that cause caution alarms, the simulation used at Memphis is expected to be more representative of operational conditions. Training and procedures can also be modified to encourage controllers to use the predictive capabilities of the PRM. In light of this, it is highly probable that monitor controllers using the PRM system operationally will have response times consistent with those measured in the Memphis tests. Therefore, only the Memphis controller response data were selected for inclusion in the collision risk model. Since the variance between controllers tested at both

sites appears to be consistent, both the Raleigh and Memphis data were used in assessing trends pertinent to the variables studied.

4.2.2 Rate of Unnecessary Breakouts

The simulation presented opportunities for controllers to break out aircraft which were not scripted to be involved in a blunder. These opportunities were of two distinct types, the deliberate and inadvertent opportunities mentioned in Section 4.2.1.3.

The deliberate opportunities included tracks deviating toward the NTZ at an angle of 5 to 20 degrees, tracks gradually drifting off course toward the NTZ, and tracks which had drifted away from the NTZ, gradually coming back toward the localizer course and then overshooting it. The inadvertent opportunities arose from normal tracks, generated from the Memphis FTE data during turbulent conditions. In these cases, a combination of radar noise and increased flight technical error created flight paths that activated the caution alert. The inadvertent opportunities more closely modeled the situation that might occur as a result of normal pilot technique. The deliberate opportunities represented more erratic piloting. The only difference between one of these and a blunder is whether the aircraft enters the NTZ before turning back to the approach course.

Table 4-9 presents the data on unnecessary breakouts collected at Memphis, Table 4-10 the data collected at Raleigh. Both are for 3,400-ft separation. The results are categorized by sensor update interval and deliberate or inadvertent opportunity. It should be emphasized that the percentages shown are unnecessary breakouts as a percentage of breakout opportunities, not percentages of total flights, which would of course be significantly smaller.

Table 4-9

Unnecessary Breakouts - Memphis Data

Update Interval	1.0 s		2.4 s	
Type of Breakout Opportunity	Deliberate	Inadvertent	Deliberate	Inadvertent
Number of Pairs of Controllers	20	20	20	20
Total Nuisance Caution Alerts	160	1380	90	1170
Total False Breakouts	14	1	11	4
Percentage of False Breakouts	8.75%	<.01%	12%	<.04%
False Breakout Rate*	87	<1	120	<4

*per 1,000 False Breakout Opportunities

Unnecessary breakouts occurred primarily from the so-called deliberate opportunities. Each of these involved aircraft approaching to within 100 or 200 ft of the NTZ, or deviating left and right of course several times. The aircraft would eventually return to course but the controller of course could not know. By breaking out either the apparent blunderer or the adjacent aircraft, the controller acted on a judgment that NTZ penetration was imminent. Because the methodology of the deliberate breakout opportunities was not standardized between the two sites, there is no direct comparability between the Raleigh and Memphis data. The results are of the same order of magnitude.

Examination of approach data collected at Memphis indicates that flight paths similar to the deliberate breakout opportunities are rare, occurring in less than 1% of the

recorded approaches. Therefore, the unnecessary breakout rate per approach, of the highest number in the tables (12%), reduces to less than about 1 per thousand.

Table 4-10

Unnecessary Breakouts - Raleigh Data
(Deliberate Blunders Only)

Update Interval	0.5 s	1.0 s	2.4 s	4.8 s
Number of False Breakout Opportunities	155	239	153	104
Total Number of False Breakouts	2	12	10	8
Percentage of False Breakouts	1.4%	5.0%	6.8%	7.7%
False Breakout Rate*	14	50	68	77

*per 1,000 False Breakout Opportunities

The inadvertent opportunities were believed more typical of an unnecessary breakout opportunity. The low inadvertent rate suggests that controllers are able to tolerate a high number of nuisance caution alerts in turbulent conditions. Because all tracks evidence small difficulties in tracking the localizer compared with calm wind conditions, controllers expected some deviations and the occasional caution alerts did not prompt them to break aircraft out unnecessarily.

Table 4-11 presents data on unnecessary breakouts at the 4.8-second update interval and compares 3,400- versus 4,300-ft runway separation. No nuisance caution alerts occurred at 4.8 seconds and 4,300 ft and therefore no unnecessary breakouts occurred, even for the deliberate opportunities.

Table 4-11

Unnecessary Breakouts - Comparison of Runway Separations at 4.8-second Sensor Update Interval at Memphis

Runway Separation	3,400 ft		4,300 ft	
Type of Breakout Opportunity	Deliberate	Inadvertent	Deliberate	Inadvertent
Number of Pairs of Controllers	14	14	12	12
Total Nuisance Caution Alerts	448	996	0	0
Total False Breakouts	5	17	0	0
Percentage of False Breakouts	1.1%	1.75%	0	0
False Breakout Rate*	11	17	0	0

*per 1,000 False Breakout Opportunities

4.2.3 Missed Approach Blunder

The missed approach blunder scenario failed to develop useful information on preventing blunders during missed approach. This scenario involved a blunder after a dual missed approach. Since most scenarios ended with both aircraft landing or with one aircraft blundering and the other breaking out, controllers witnessing a dual missed

approach -- a rare event in actual operations -- acted to resolve any possibility of a missed approach blunder by turning the aircraft away from each other before a blunder occurred. This occurred in both live flights and simulations.

4.3 Changes to Controller Procedures

4.3.1 Facility Orders for PRM Flight Tests

At both Raleigh and Memphis, testing of the PRM systems included flight tests involving company or FAA aircraft. In order to carry out flight tests at commercial airports safely and without significantly impacting normal operations, special procedures are required. The procedures established at Memphis and Raleigh addressed issues of safety and of coordination between ATC personnel, flight test aircraft, and PRM site staff.

Site specific facility orders were developed by the Air Traffic Managers at each airport for use when flight tests were in progress, particularly when staged deviations from the ILS approach course were planned. The orders are reproduced in Appendix C.

4.3.2 Proposed Changes to Controller Handbook

Proposed procedural changes for PRM embody the procedures currently in use for simultaneous independent approaches to parallel runways separated by at least 4,300 ft. Additional requirements include the responsibility to monitor the approaches to one-half nautical mile beyond the departure end of the runway; limitations on the duties of the monitor controller, i.e., he may not be delegated the responsibility for longitudinal separation on the same final approach course, and the necessity for a PRM system at those airports with parallel runways separated from 3,400 to 4,300 ft.

Appendix D shows recommended changes to the controller handbook procedures specific to simultaneous ILS approaches to parallel runways separated by 3,400 ft to 4,300 ft. Additional procedural changes may be provided should simultaneous ILS approaches to smaller runway separations be approved.

4.4 Controller Display Acceptance

Controller survey forms were used at both sites to solicit the opinions of the controllers on the effectiveness of the PRM system and its overall acceptability for use. On the first day of a controller's participation in the study, the controllers were given a copy of an opinion survey which was to be completed at the end of the week. This was done so that throughout the week they could be mindful of the various areas in which their opinions were needed. On Friday, after all testing was completed, each controller filled out the survey. Surveys were completed by 50 controllers who participated at Memphis and 50 controllers who participated at Raleigh. Findings at both sites were very similar. In reporting the results of the survey, responses from both sites were pooled.

The controllers who participated at both sites expressed overall approval with the PRM system. Controllers made some recommendations regarding personal preferences in the manner in which information was presented on the display.

Table 4-12 lists the percentage of controllers who agreed, disagreed, or were undecided regarding each survey statement. The complete text of each survey statement is also presented, accompanied by a summary of results and any narrative comments made by the controllers.

Table 4-12

Summary of Controller Survey Results
from Combined Memphis and Raleigh Studies

Survey Item	Agree (%)	Disagree (%)	Undecided (%)
2. GENERAL ACCEPTANCE			
2.1 Monitor final better than ARTS	100	0	0
2.2 High resolution color display better for monitor function than ARTS display	100	0	0
2.3 Automated alerts made it easier to detect and resolve blunders	100	0	0
2.4 Approaches with runways separated by 3,400/3,500 can be safely conducted	95	0	5
3. MONITOR CONTROLLER FUNCTIONS			
3.1 PRM is useful to prevent NTZ penetration	96	3	1
3.2 PRM is useful in resolving blunders	96	3	1
3.3 PRM is useful in detecting deviations	100	0	0
3.4 PRM is useful in monitoring the missed approach	90	4	6
4. NTZ ALERTS			
4.1 Yellow caution alert is useful	99	1	0
4.2 Voice alert is useful (Memphis only)	98	2	0
4.3 Red warning alert is useful	98	0	2
5. DISPLAY INFORMATION CONTENT & PRESENTATION			
5.1 Information on display is well placed and useful	96	2	2
5.2 Written information on display is easily read	97	2	1
5.3 Color is better than monochrome	98	0	2
5.4 Vertical or horizontal rotation of display is sufficient rotation (Raleigh only)	70	14	16
5.5 Parallel 200 ft lines are useful	81	11	8
5.6 Color selection of features is suitable	95	3	2
6. FEATURES			
6.1 History Trail	80	12	8
6.2 Projected Position Vector	95	1	4
7. TRAINING			
7.1 Training time was adequate	95	1	4
7.2 All information was provided	96	4	0
8. SIMULATION			
8.1 Simulated traffic density was realistic	97	3	0
8.2 Simulated blunder trajectories were realistic	48	42	10
8.3 Simulated missed approach trajectories were realistic	62	27	11
8.4 Audio portion of simulation was realistic	86	11	3

Survey Section 2 General Acceptance

Statement 2.1 PRM enabled me to monitor the final approach better than the existing ARTS system.

Statement 2.2 PRM's high resolution color monitor is better for the monitor function than the current ARTS system.

Statement 2.3 The PRM display with the automated alerts made it easier to detect and resolve potential and actual blunders/deviations better than the existing ARTS system.

One hundred controllers unanimously agreed with the above three statements. Controllers made comments indicating a high level of acceptability of the system. The comments of many controllers were similar to this comment made by one controller, "the PRM system is very impressive and the system should be implemented as soon as possible to airports that need to relieve congestion, controller workload and, most importantly, to enhance safety." When comparing the PRM system to the current ARTS system, controllers described PRM as being: "a vast improvement," "far superior," "much better," "more accurate," " a thousand times better."

Controller comments on the automated alerts indicated unanimous approval. Comments included: "the alerts are invaluable when considering ambient noise and distractions," and "visual and audible alerts are an absolute must."

Statement 2.4 Independent IFR approaches to runways separated by 3,400/3,500 ft can be safely conducted using the PRM.

Ninety-five controllers agreed with this statement. The five controllers who were undecided indicated that before making a decision, they would have liked more time in which to become familiar with the system.

Survey Section 3 Monitor Controller Functions

Statement 3.1 PRM is useful as a final approach monitor to prevent penetration of the NTZ.

Ninety-six controllers agreed with this statement. Many controllers stated that the combination of the shorter sensor update interval and the presence of warning alerts greatly improve the safety of this type of operation.

Statement 3.2 PRM is useful in resolving approach blunders once they have occurred.

Ninety-six controllers agreed with this statement. Comments from the controllers who disagreed or were undecided emphasized the need for new procedures to be developed for conducting simultaneous parallel approaches.

Statement 3.3 PRM is useful in detecting deviations from the designated approach course.

One hundred controllers unanimously agreed that PRM is useful in detecting deviations from the designated approach course. Controllers commented on the benefits of increased magnification. One controller's comment summarizes what many of the controllers expressed, "the increased magnification makes minute deviations more readily detectable."

Statement 3.4 PRM is useful in monitoring simultaneous missed approach to ensure that the required divergence is achieved.

Ninety controllers agreed with this statement. Based on the comments from controllers who either disagreed or were undecided, they were not saying that PRM is not useful in monitoring the missed approach. They commented that monitoring the missed approach should be the responsibility of the local controller and not the monitor controller.

Survey Section 4 NTZ Alerts

Statement 4.1 The Yellow/Caution Visual Alert, predicting x seconds or less until NTZ penetration, is useful.

Ninety-nine controllers agreed with this statement. The one controller who disagreed on its usefulness, reported having difficulty seeing the yellow color when he was not looking directly at the particular aircraft ID which was yellow. No other controller reported having this difficulty.

Statement 4.2 The Voice Alert accompanying the Yellow/Caution Visual Alert is useful (Memphis only).

This statement was answered by the 50 controllers who participated at Memphis, where a voice alert was used. All but one controller agreed that the voice alert was useful. The one controller who disagreed reported preferring a "beep" which would be heard external from the headset audio.

Statement 4.3 The Red/Warning Visual Alert, indicating that NTZ penetration has occurred, is useful.

Ninety-eight controllers agreed with this statement. Comments from the controllers who agreed, described the Warning Visual Alert as: "a must for this system," "a key component of the entire process," "a confirmation of the decision that you have just made." Two controllers were undecided. One of the undecided controllers stated that he believed the red/warning alert was not necessary since, "the decision to abandon a parallel ILS must not be delayed until transgression has occurred, but must be made when it is reasonably certain that transgression will occur."

Survey Section 5 Display Information Content and Presentation

Statement 5.1 The information presented in the PRM display is well-placed and easily visible.

Ninety-six controllers agreed with this statement. Two controllers were undecided and two controllers did not agree. One controller stated that the system should include a control to adjust character size in accordance with individual preference. In general, the controllers made comments referring to the information presentation as being: "a very good design," "excellent," etc.

Statement 5.2 The written information presented in the PRM display is easily read.

Ninety-seven controllers agreed with this statement. Two controllers who disagreed stated that the menu was "cluttered." Their disagreement referred to the menu and not the readability of the display text. The menu structure was not under

study in this experiment. The current menu structure is lengthy, since it includes items which are used by the experimenter in setting up the simulation. The actual menu that will be seen by a Monitor Controller will be greatly streamlined.

Statement 5.3 The color display is more effective than a monochrome display.

Ninety-eight controllers agreed with this statement. Two controllers were undecided.

Statement 5.4 The ability to rotate the runways from the actual runway orientation to either the vertical or horizontal is a sufficient rotational capability (Raleigh only).

This statement was answered by controllers who participated at Raleigh. Of the controllers who responded, the majority of controllers agreed with this statement. Several of the controllers who disagreed or were undecided stated a preference for being able to rotate the map to the magnetic heading of the runway in use.

Statement 5.5 The parallel 200-ft lines are a useful aid in detecting deviations from the approach course, and in predicting the potential for an NTZ penetration.

Eighty-one controllers agreed that the lines are useful. The majority of controllers stated that the lines help to detect deviations at the earliest time. Of the controllers who disagreed, several stated that they did not use the lines and found them to be "unnecessary clutter." One controller suggested increasing the distance between lines, thereby reducing the number of lines. Of the controllers who were undecided, some controllers stated that the lines should be optional, and expressed that some controllers would benefit from their use and some would not.

Statement 5.6 The color selection for the features on the display is suitable.

Ninety-five controllers agreed with this statement. Of the controllers who disagreed or were undecided, a few controllers commented that the predictor lines should be a color which would "standout" more.

One controller commented that the yellow used for the Caution Alert should be "much brighter." This was the same controller, discussed above (Statement 4.1), who had difficulty seeing the yellow color when he was not looking directly at the particular aircraft ID which was yellow. No other controller reported having any difficulty seeing the color yellow. This one controller's difficulty perceiving the yellow color illustrates the value of having redundancy in the alert system. In addition to visual, color-coded alerts, there are accompanying audible alerts.

Survey Section 6 Features

Statement 6.1 The History Trail is useful in assisting you to perform the Monitor Controller task.

Eighty controllers agreed that it is useful. Of the controllers who disagreed or were undecided, many stated that the use of this feature should be a matter of personal preference.

Statement 6.2 The projected Position Vector is useful in assisting you to perform the Monitor Controller task.

Ninety-five controllers agreed that it is useful. Many controllers stated that this feature is one of the best aspects of the system. One controller stated that "it helped me enormously in decision making while tracking aircraft." Five controllers disagreed. Of the controllers who disagreed, a few felt it was of no use at all and a few felt that its use should be a matter of personal preference.

Survey Section 7 Training

Statement 7.1 Adequate training time was provided to become familiar with the display before beginning the testing.

Ninety-five controllers agreed with this statement. Controllers who disagreed stated that they would have liked a little more time working with the display before beginning testing.

Statement 7.2 All information needed, to aid me in performing the monitoring task, was provided.

Ninety-six controllers agreed with this statement. Overall, controllers commented that the training was "excellent" and that "there was always someone there, if a question or concern arose."

Survey Section 8 The Simulation

Statement 8.1 The simulated traffic density was realistic.

Ninety-seven controllers agreed with this statement. The controllers who disagreed commented either that there were "too many perfect side by side approaches" or that there should have been "more bumps into the NTZ."

Statement 8.2 The simulated aircraft "blunder" trajectories were realistic.

Controller opinion was split on this item. Most controllers who disagreed gave one of the following reasons:

1.) Some controllers found it difficult to adjust to the magnification of the x and y axis. The magnification makes the angle of the deviation appear more severe than it actually is. Some controllers commented that the angle of deviation was too great, and therefore, unrealistic. In the simulation the angle of the deviations did not exceed 30 deg, but some controllers said that it was greater.

2.) Some controllers said that there were too many emergencies and that this was unrealistic. The simulation did intentionally show many more blunders than one would experience in actual operations. Actual blunders are infrequent and, therefore, difficult to study. Through simulation a number and variety of blunders were presented in order to obtain valuable data on controller responses.

Statement 8.3 **The simulated aircraft missed approach trajectories were realistic.**

The majority of controllers agreed with this statement. Many controllers who disagreed stated that the scenarios which depicted two aircraft on adjacent approach paths, making a simultaneous missed approach, and then simultaneously blundering toward the NTZ, i.e., toward each other, was highly unlikely. Some controllers commented that, since the probability of this event is so small, this event should not have been included in the scenarios.

Statement 8.4 *The audio portion of the simulation was realistic.*

The majority of controllers agreed with this statement. For the recorded audio, used in Memphis, one controller and one pilot spoke the parts of all pilots and all local controllers. One controller who disagreed commented that the voices were too monotonous. A few controllers commented that the background audio was "too wordy." Regarding the audio portion used at Raleigh, the audio did not include tower conversation on the frequency and a few controllers commented that it should have been included.

Survey Section 9 Comments

Controllers were asked to comment on any changes to the simulation which might enhance its realism. Controllers suggested simulating the actual work environment that they experience. They sited the presence of many more distractions in a live TRACON. Controllers commented that more speed changes should be included in the simulation. Approximately three speed changes per hour were scripted into the Memphis simulation.

Controllers were asked to identify any factors in the simulation which might have affected the quality of the reaction time measurement. Some controllers commented that there were many more blunders than one would encounter during actual monitoring. One controller commented that this created stress and may have slowed his responses. Another controller commented that this heightened his anticipation and may have quickened his responses.

Controllers were asked to make any additional comments regarding the simulation, the display, or the study procedures. Many positive comments were received. Controllers reported being impressed with the system and generally stated that it should be implemented as soon as possible.

Some concerns were voiced by controllers. The controllers preferred the 0.5, 1.0, and 2.4-second sensor update intervals to the 4.8-second sensor update interval. The 4.8-second sensor update interval was said to be "too slow." There was also concern that problems may be encountered with frequency congestion, especially when the 4.8-second sensor update interval is used. There were fears that the controller's communication transmission may be blocked at a critical time by an aircraft transmitting on the frequency. There were also concerns that in using the 4.8-second sensor update interval, many unnecessary corrective headings may have to be issued.

5. COMMUNICATIONS

Highlights

- **On average, a blunder resolution instruction waits much less than one second for a clear communications channel, based on data measured at both Memphis and Chicago.**

PRM blunder resolution depends on the controller being able to speak to the endangered aircraft pilot without delay. This chapter describes the communication frequencies and switching in use with independent parallel approaches today and reports on a study to characterize the availability of the channel when the monitor controller requires it.

5.1 Today's Configuration

As an aircraft approaches an airport with a TRACON and a tower, it may talk to several approach controllers as it passes through terminal airspace. Working backward from landing, the last position in the facility to talk with the aircraft is the tower, or local controller. Before that, the aircraft is controlled by the final controller, who directs it onto the final approach course, and issues an approach clearance. When a monitor controller is necessary to monitor simultaneous independent approaches, that controller speaks over the tower or local control frequency. The monitor controller has the necessary equipment to override the local controller: that is, if the monitor controller transmits, any transmissions in progress by the local controller are superseded by the monitor. In most cases of independent parallel approaches, each runway has a separate local controller, monitor controller, and local control frequency.

5.2 Impediments to Communication

There are two categories of problems which could prevent immediate communication with one of the aircraft involved in a blunder. The first is a prolonged communication unavailability, and the second is a more temporary one.

The prolonged failure could be created by radio equipment failing, being turned off, turned down, or tuned to the wrong frequency. A radio could be stuck in the transmit position, blocking the frequency for other uses. No data are available on how often these situations occur, but it is clear that failures lasting more than a minute or two would result in suspension of simultaneous approaches. The first few minutes of prolonged failure are addressed in the demonstration by assuming that the blundering aircraft could not be corrected. As each parallel runway is usually assigned its own frequency, the likelihood of a failure of both frequencies, coincident with a blunder, is extremely remote.

A temporary unavailability could result if the call sign of an aircraft is misspoken by the controller or misheard by the pilot, or if another aircraft is transmitting on the frequency. While misidentified or blocked transmissions occur in the system today, they are minimized by reducing the number of aircraft on the frequency, by the frequency users' awareness of the critical nature of a blunder resolution instruction, and by prompt followup on the part of the originator if a message is not acknowledged. The frequency is also temporarily unavailable to the controller when an aircraft is transmitting. This occurred

once during the PRM aircraft demonstrations. The controller began transmitting the blunder resolution instruction at the same time that an uninvolved aircraft began an unrelated transmission. Although the monitor can override the tower, an aircraft transmitting back to the tower cannot be overridden. This source of communications unavailability was measured at two airports.

5.3 Data Collection

Communications over local control frequencies were recorded in January, 1989 during periods of peak arrival traffic at Memphis and Chicago O'Hare International Airports. Dependent approaches are conducted at Memphis, while independent simultaneous approaches are conducted at Chicago. The lengths of all non-controller transmissions were extracted from the audio recordings. These were used to calculate statistics on pilot transmissions for each airport, as well as to create probability distributions of how long a monitor controller might have to wait before transmitting due to a blocked communications frequency.

5.4 Data Analysis

The data from Memphis were for 105 arrivals, 27 departures, one missed approach and one IFR void time conversation. Total air time was 105 minutes. There were 470 pilot transmissions, with an average duration of 1.8 seconds. The shortest communications were 0.2 seconds and the longest was 8.3 seconds. Total pilot transmit time was 14 minutes, or 13.4% of the air time. Arrivals to both runways are included in these data, because simultaneous approaches are not conducted in IMC and there is only one local controller and a single local control frequency.

The data from Chicago were for a single runway and local control frequency only. For this runway, there were transmissions from 75 arrivals, one departure, one helicopter and two land vehicles. Total air time was 114 minutes. There were 253 transmissions, with an average duration of 1.6 seconds. The shortest communications were 0.1 seconds and the longest was 4.6 seconds. Total pilot transmit time was 6.8 minutes, or 6% percent of the air time.

There were many more pilot transmissions recorded per hour at Memphis than at Chicago because one local controller monitored both runways. Yet, the shape of the transmission distributions are similar, with the majority lasting less than 3 seconds. Mean durations at both sites are also the same. The distributions of pilot transmission lengths are shown in Figure 5-1.

Probability curves for the length of time a monitor controller may have to wait before being able to access the local frequency can be derived from the above distributions. The need of the monitor controller to access the local frequency is independent of the occurrence of a pilot transmission. Thus, if a controller needs to speak while a pilot is transmitting, the moment at which the decision is made will be at a random point during the transmission. It is very unlikely that the controller will have to wait the entire length of the pilot transmission. For example, assume a pilot transmission of five seconds. If the controller decides, two seconds into the transmission, that he needs to access the communication frequency, then he will have to wait three seconds before the channel is free. If the controller makes his decision four seconds into the pilot transmission, then he will have to wait only one second. Applying this logic to the data collected at both sites, one can estimate the probability that the monitor controller will have to wait between 0.1 and 8.3 seconds, before having access to the local frequency. The probability distributions of delay time due to pilot transmissions are shown in Figure 5-1.

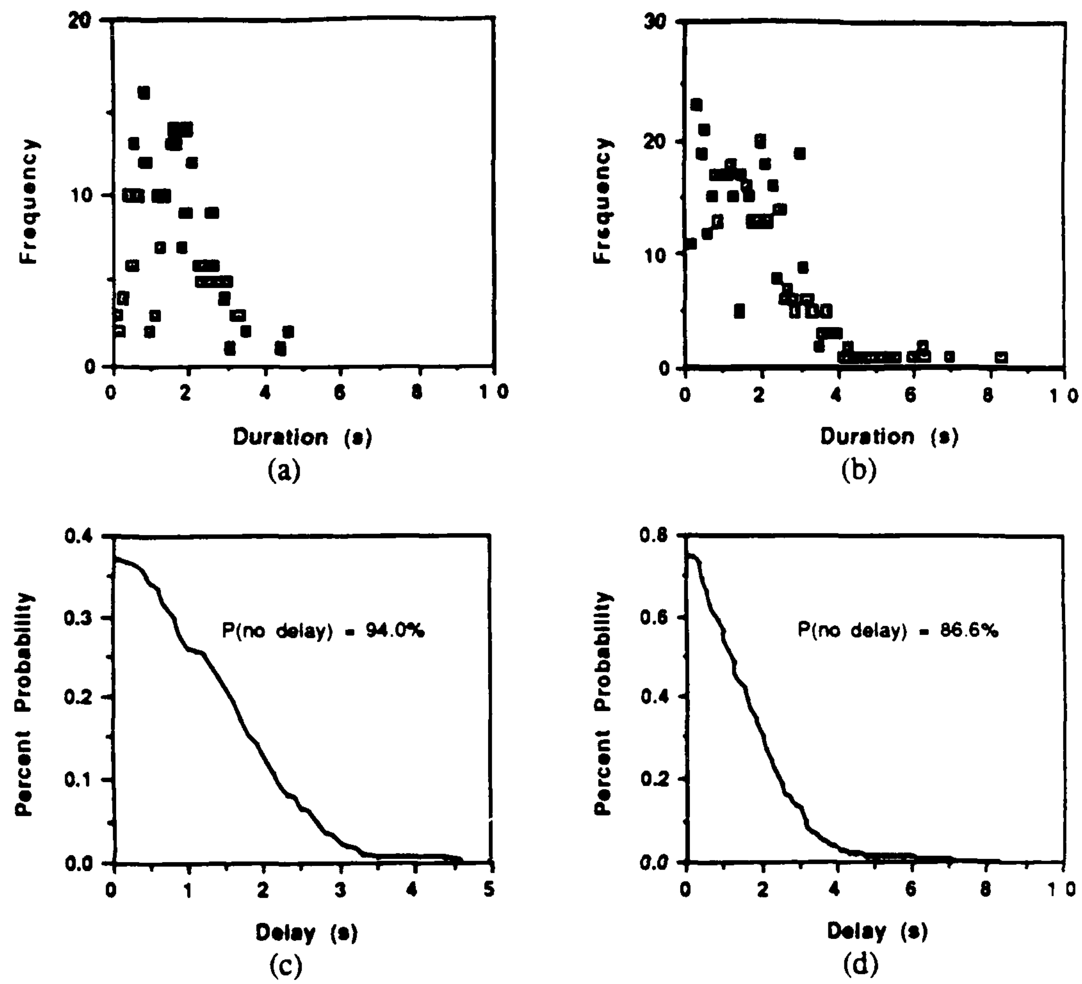

Figure 5-1. Pilot transmission data. Duration of pilot transmissions are shown in (a) for Chicago O'Hare and (b) for Memphis. Probability distributions for controller communication delay due to pilot transmissions are shown in (c) for Chicago O'Hare and (d) for Memphis.

The communication delay probability distributions are used in the collision risk model to model the effect of a blocked communications channel on blunder resolution. The model is described in Chapter 7.

6. PILOT/AIRCRAFT

Highlights

- **There was significant variation in the time pilots take to react to the breakout command. Flight crews also tended to act more conservatively than necessary from aerodynamics considerations, some reacting as if flying a normal missed approach procedure.**
- **Additional training or familiarization will be required for flight crews who will be involved in simultaneous ILS approach operations.**
- **Response times in live aircraft demonstrations were consistent with or faster than the data from flight simulator studies.**
- **Pilots were impressed with the PRM, and with the ability of controllers to use it to detect deviations.**

A major component of the actions leading to a successful blunder resolution is the response time of pilot and aircraft. This is defined as the time from the beginning of the controller breakout instruction until the aircraft starts a turn. The response time was studied in transport aircraft: Boeing 727, McDonnell Douglas MD 80, and widebody McDonnell Douglas DC10. Aircrew responses were measured early in the approach, when aircraft are flying at several thousand feet altitude and well above stall speed, as well as just before landing, when both altitude and speed are significantly decreased.

Air transport flight simulators were used to gather much of the data. One set of experiments measured the pilot/aircraft response to a controller-directed breakout. Other experiments connected the flight simulator outputs to the PRM display, and the pilot's audio to a controller viewing the display. Data were also taken for live aircraft during approaches monitored by the PRM radar and displays.

6.1 Flight Simulator Studies

6.1.1 Stand Alone Flight Simulator Studies

Pilot/aircraft response was studied with the FAA's B727 flight simulator in Oklahoma City (OKC) and the Federal Express DC10 flight simulator in Memphis. Airline and FAA pilots participated in the tests. An air traffic controller provided routine communications and breakout instructions. The subject pilots flew a series of straight-in approaches to Memphis runway 36L under instrument meteorological conditions (IMC). One fifth of the approaches resulted in a landing. On the remainder, the breakout instruction was issued by the controller at or just prior to one of three points on the approach: (1) 100-ft decision height (DH), (2) 200-ft DH, or (3) six nautical miles out on the approach (intermediate approach segment). The preflight briefing indicated that on

some approaches pilots would be told to turn "immediately," but they were not instructed in how to fly the aircraft in response to that request.

Digital tape recordings were made of simulator track data (x, y, altitude) as well as aircraft parameters such as bank angle and engine thrust, allowing an assessment of the order of events that occur during crew response. The data are in one-second time increments. Start of turn was designated as the point at which the bank angle exceeded three degrees.

6.1.1.1 B727 Study

Table 6-1 presents the data. The columns differentiate data for pilot/aircraft responses to breakout instructions issued at different points on the approach. The first row shows the altitude at which the controller began the instruction. The distribution of pilot/aircraft response times between breakout instruction and start of turn is shown in Figure 6-1.

Table 6-1

B727 Crew Performance Statistics.
(OKC Study)

Statistic	100-ft DH N = 39	200-ft DH N = 36	Six nmi out N = 33
Altitude at Start of ATC Instruction (ft above ground level)	208 - 318	257 - 329	1636 - 2066
Time between ATC Instruction and Start of Turn (s)	7.3 ± 4.5 (2, 22) *	4.9 ± 2.8 (2, 13)	4.5 ± 2.9 (2 , 16)
Time between ATC Instruction and Increased Engine Pressure Ratio (s)	3.6 ± 1.3 (2, 7)	3.8 ± 1.6 (2, 9)	5.5 ± 2.9 (2, 16)
Maximum Bank Angle (deg)	28.3 ± 3.8 (19.2, 36.5)	29.2 ± 4.7 (15.6, 38.0)	32.3 ± 4.9 (21.9, 42.8)
Maximum Turn Rate (deg/s)	3.6 ± 0.6 (2.2, 4.7)	3.8 ± 0.7 (2.1, 5.2)	4.2 ± 0.9 (2.7, 6.4)

* Mean ± 1 standard deviation. Numbers in parentheses are minimum and maximum values

The variation among pilots in the response times is of considerable interest. There were three subject pilots who exhibited response times that far exceeded the average time between the ATC turn command and start of turn. Upon examination, these pilots consistently exhibited slow response times to ATC-directed turns, even for the six-mile out scenario. For the scenarios at DH, these pilots flew to 1,000 ft mean sea level (MSL), the published turn altitude, before initiating a turn, rather than turning as soon as possible.

The response time was affected by the altitude on the approach at which the turn command was given, especially at the lowest altitude. Pilots and aircraft took half again as long to respond in the 100-ft DH scenario as in the 200-ft DH and intermediate scenarios. The differences are related to aircraft configuration, altitude and speed. More time is required close to the runway to achieve a safe altitude and speed for turning. While it may take more time for an aircraft to turn away from the approach path close to the runway, it may also be less likely that an aircraft will be broken out from an altitude less than 300 ft above the runway. At this altitude, the aircraft is less than one mile from touchdown and, depending on weather conditions, could land before a blunder had progressed far enough

that the two aircraft could collide. Thus, slow pilot response close to the runway is not a critical consideration for implementing the PRM because the monitor controller has the option of allowing the aircraft to land.

For the low altitude breakouts, the engine pressure ratio (EPR) and attitude data gave earlier evidence of pilot response. Three primary events occur in the crew/aircraft response: (1) pitch is changed to achieve a climb attitude, (2) engine thrust (EPR) is increased to halt aircraft descent and begin a climb, and (3) when the crew feels it is safe to do so, the aircraft is turned to the required heading. Generally, for aircraft on final approach and near decision height, engine thrust and altitude must increase before the crew is comfortable making the turn. For the lowest altitude breakouts, the EPR increase came nearly four seconds before the bank is detected. For aircraft further out, altitude and speed are not a problem and the turn may be initiated before the other two events.

In general, a maximum bank angle of 30 degrees and a maximum turn rate of greater than 3 degrees per second were achieved. Some crews limited their responses to a bank angle of less than 20 degrees and a turn rate of less than 2.5 deg/s.

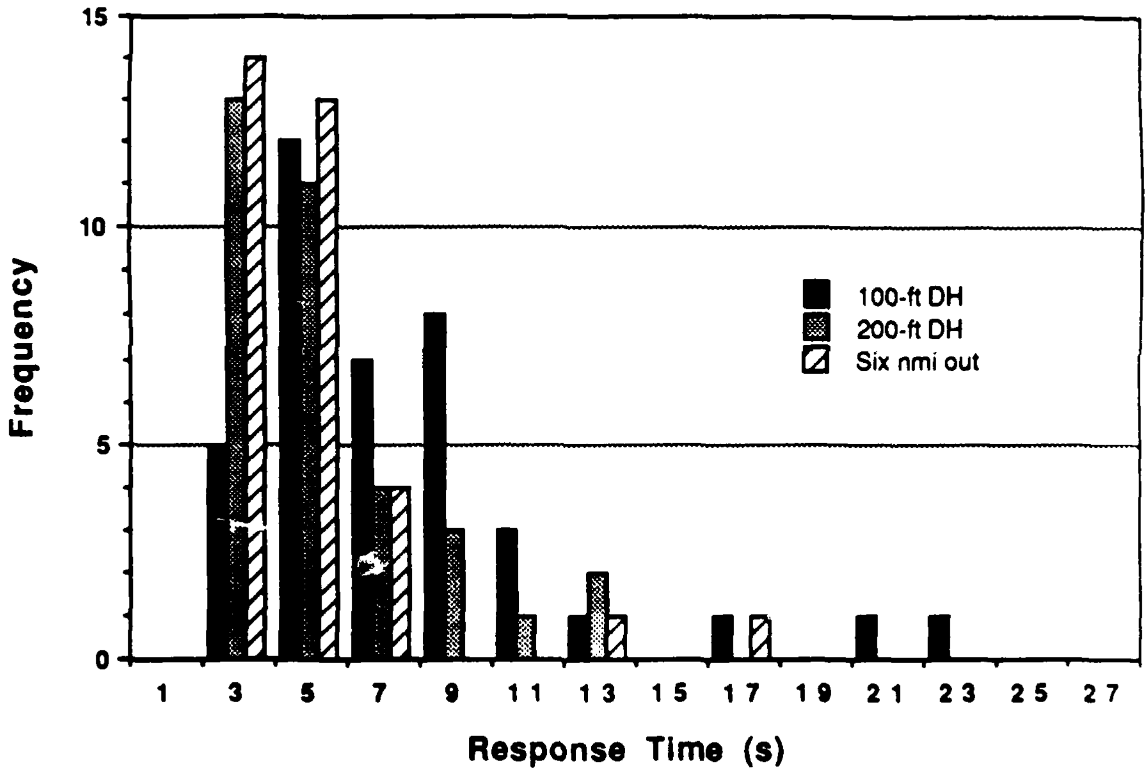

Figure 6-1. Time to B727 start of turn for the OKC flight simulator study.

6.1.1.2 DC10 Study

Table 6-2 presents the start of turn statistics for the DC10 study. The columns differentiate data for the three scenarios. As with the B727 response times, there were a few pilots who consistently exhibited slow response times for all scenarios. The distribution of pilot/aircraft response times between breakout instruction and start of turn is shown in Figure 6-2. This distribution is similar to that for the B727 shown in Figure 6-1.

Table 6-2

DC10 Crew Performance Statistics.
(OKC Study)

Statistic	100-ft DH N = 34	200-ft DH N = 31	Six nmi out N = 14
Time Between ATC Command and Start of Turn (s)	6.8 ± 4.5 (2, 27)*	3.7 ± 3.7 (1, 17)	4.7 ± 6.0 (1, 23)
Altitude at Start of ATC Command (ft AGL)	165 - 244	197 - 339	1390 - 1616

* Mean ± 1 standard deviation. Numbers in parentheses are minimum and maximum values

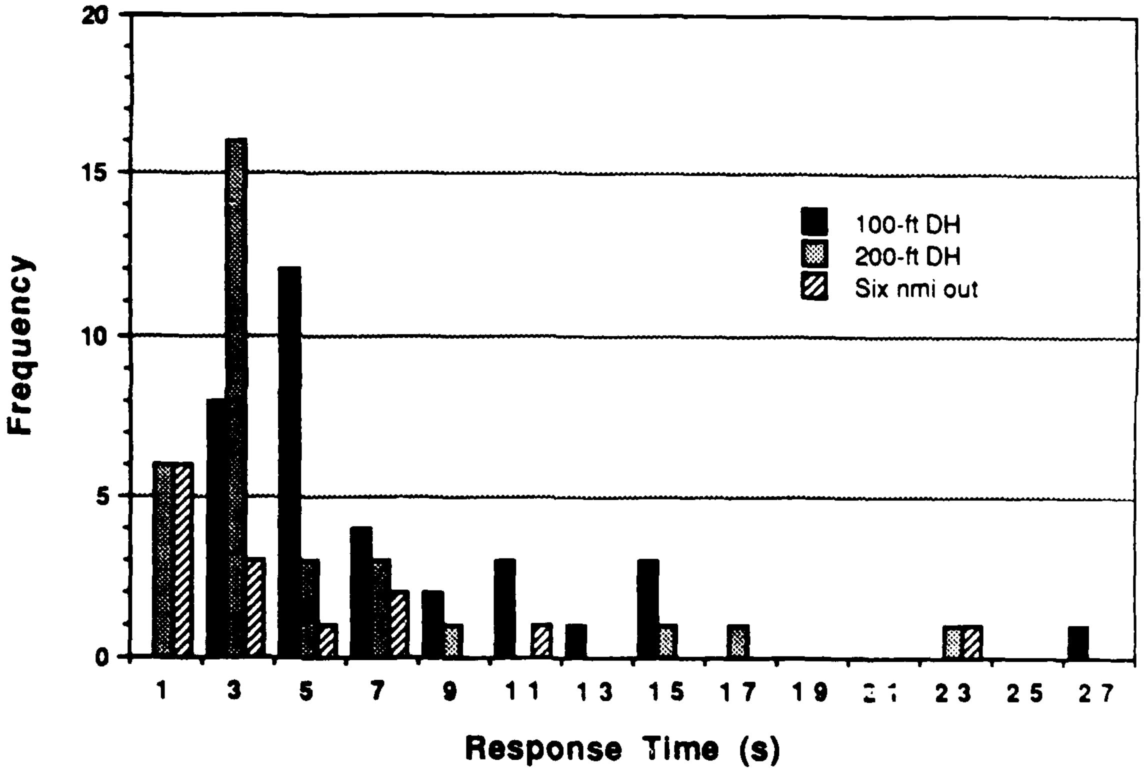

Figure 6-2. Time to start of turn for the DC10 flight simulator study.

6.1.2 Flight Simulators in the Raleigh Studies

6.1.2.1 Experimental Design

Pilot/aircraft response was also measured during the Raleigh controller response study. Qualified crews flew either the FAA B727 simulator or an American Airlines MD80 simulator. The flight simulator position and altitude were linked to the PRM display, and the simulator pilot audio was connected to the monitor controller's microphone. Several scenarios involving blunders at various locations on final approach and missed approach

were used to assess crew performance and to determine whether the endangered aircraft could be safely vectored out of its approach stream by the monitor controller. More information on the experimental design is found in Section 4.1, which describes the design of the Raleigh controller response measurements.

Flight simulator data from Raleigh were limited to the track data (x, y, altitude) recorded in time increments dependent on the radar update interval being simulated at the time. Start of turn was marked at the first update interval at which a one-degree per second turn rate was observed.

6.1.2.2 Results from Raleigh Simulations

Data to measure the pilot response were taken from the tracks of the flight simulators, as displayed on the PRM. The tracks are divided into two groups: those that were inside the outer marker (OM) at the time the breakout instruction was given, and those that were outside the OM. The distributions of pilot response times from the start of the ATC command to start of turn are shown in Figures 6-3 and 6-4. In general, the shape of the distributions is similar to the OKC distributions: the majority of the aircraft turned within 15 seconds of the ATC instruction.

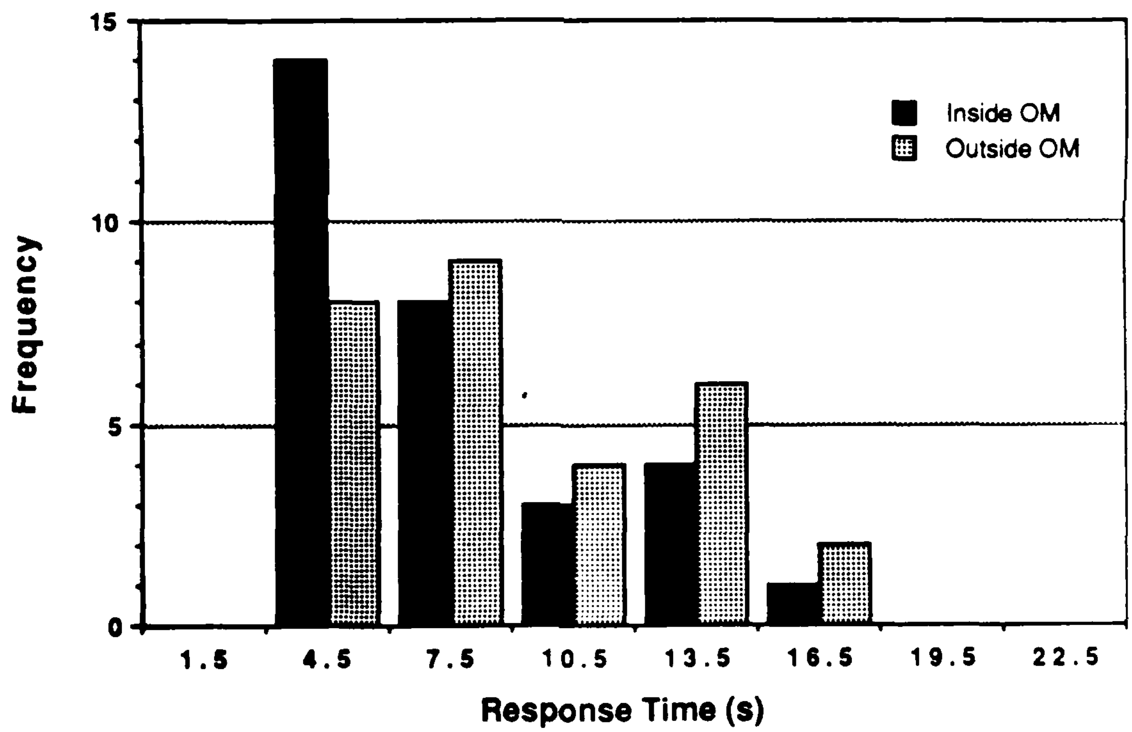

Figure 6-3. Pilot response times for Raleigh B727 flight simulator tracks.

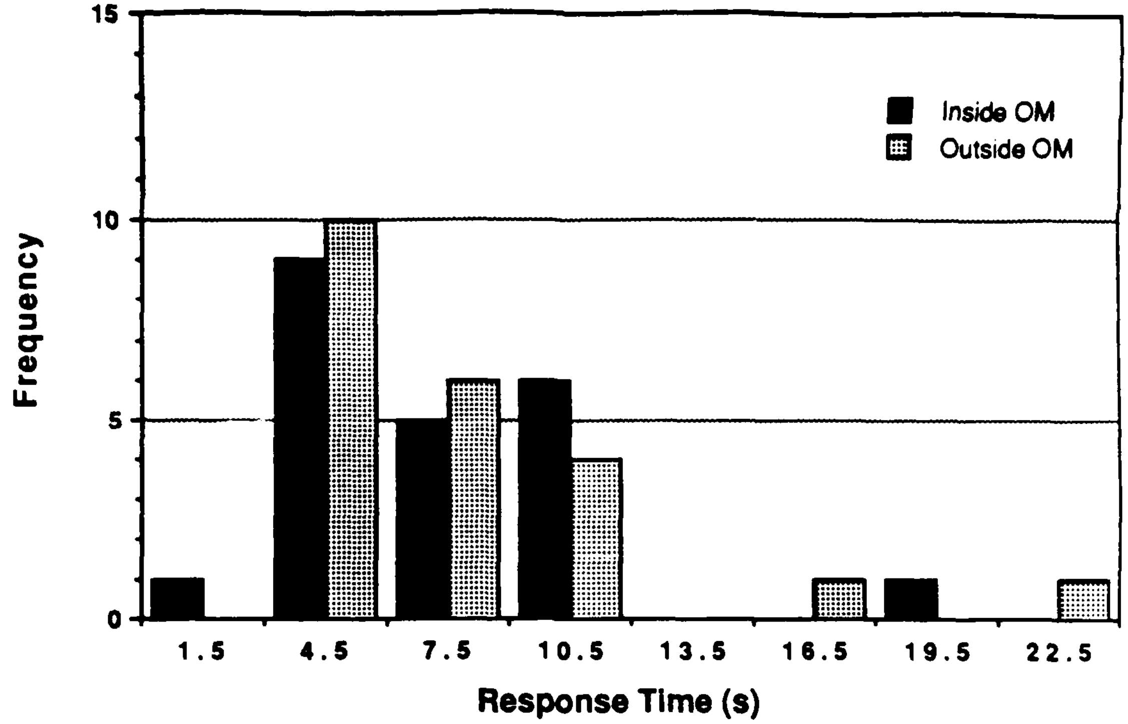

Figure 6-4. Pilot response times for Raleigh MD80 flight simulator tracks.

Those trials for which pilot response time was much slower than average have been reviewed to identify contributing factors. Two factors are:

(a) Reliance on unfamiliar equipment in the B727. Individual airlines have the cockpit layout tailored to their own requirements. Since the pilots recruited for the study were not all from the same source, there were variations in familiarity with the specific layout in the OKC flight simulator. This should not be a problem for actual commercial flights.

(b) Procedural difficulty in disabling the MD80 autoland mode during breakout. Some pilots had difficulty disengaging autoland and returning the aircraft to manual control. This problem can be alleviated by specific periodic training.

6.2 Live Aircraft Studies

6.2.1 Experimental Design

Blunder simulations using live aircraft, radar, and controllers were conducted at Memphis and Raleigh. A Convair 580 and a Boeing 727-100 were provided by the FAA Technical Center.

Testing was performed in visual conditions under visual flight rules during periods of low traffic. All pilots knew that the purpose of the tests was to measure the ability of the PRM to resolve blunders, and that the Convair would blunder towards the B727. Subject pilots were solicited from the air transport community to fly the B727. The Convair crew and the flight engineer and pilot in command of the B727 knew when the blunders would

occur, but the subject pilot did not. The aircraft were vectored onto simultaneous parallel approaches positioned relative to each other so that an uncorrected blunder would cause the aircraft to collide. Safety pilots on both aircraft maintained visual contact. In addition, the Convair pilot responded to the monitor controller by turning away at his direction.

Three blunder scenarios were conducted in random order as many times as possible during each test period: (a) a 15-degree blunder outside the outer marker, (b) a 30-degree blunder about two nautical miles inside the outer marker, and (c) a 15-degree blunder one to two nautical miles beyond the missed approach point.

6.2.2 Results

The B727 tracks from blunder scenarios flown inside and outside the outer marker (OM) were analyzed for the time delay from the start of the ATC command to the time at which the B727 achieved a one degree per second turn rate. The results are shown in Figure 6-5. There is a bias in these results compared with the flight simulators because the crews were cognizant of the Convair's maneuvers and were prepared to turn away. All crews responded within 15 seconds of the ATC command. Proximity to the runway does not appear to be a factor in time to start of turn. Because of the measurement and quantization errors inherent in live radar data, other aircraft response characteristics were not analyzed.

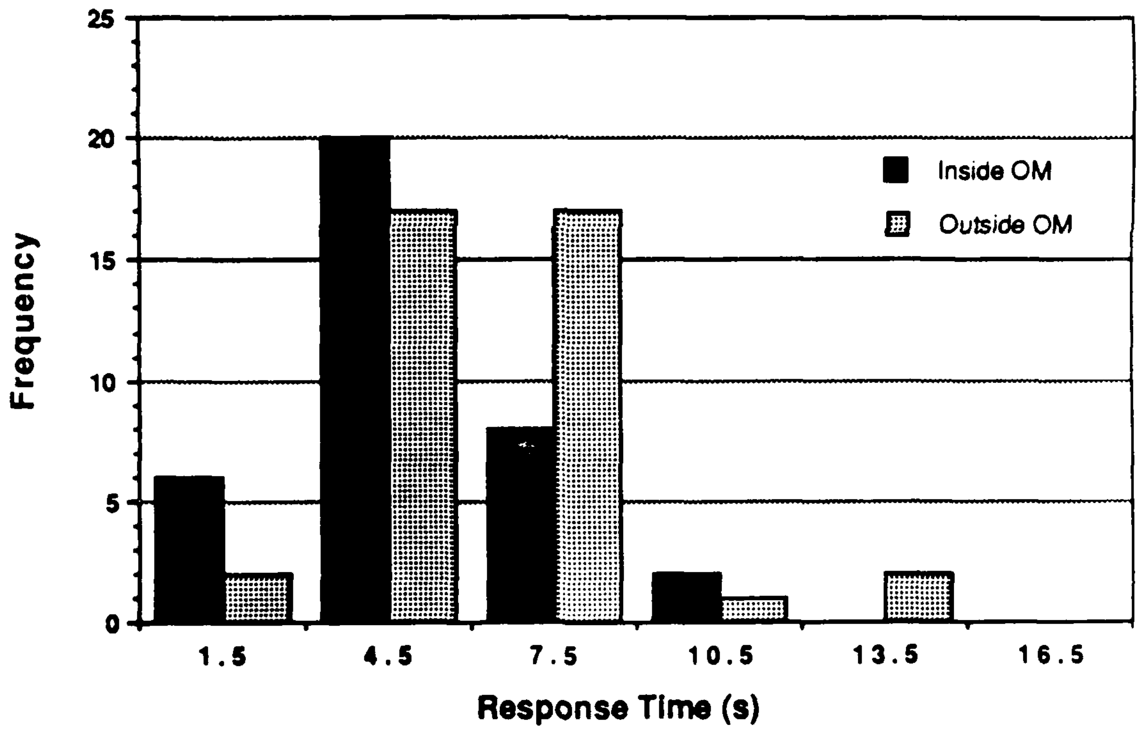

Figure 6-5. Live demonstration pilot response times.

6.3 Comparison of Pilot/Aircraft Response Data

The pilot/aircraft response data come from three sources that had different design goals. The Oklahoma City studies were expressly designed to measure the endangered aircraft's response to an ATC turn command, and were optimized for this purpose. The Raleigh data were part of a more complex study whose main goal was to measure

controllers' responses to the PRM alert system. The complexity of the experimental design limited data collection and analysis. The live aircraft data were from flights whose purpose was to demonstrate the PRM system to the user community, to confirm the more numerous trials in flight simulators, and to uncover any problems which could result from putting all the elements of the system together at one time.

Regardless of the differences in the experimental designs, the distributions of pilot response times are similar for all sources of data and types of aircraft. Even at low altitudes relative to ground, the majority of pilots can turn the aircraft within 15 seconds of the start of the ATC instruction. The size of the aircraft is not a factor in the timeliness of the response.

Situational awareness does seem to affect the quality of the pilot's response. All the pilots in the live aircraft were aware of the potential consequences of not responding immediately, and all responded within 15 seconds. With the flight simulators, some pilots did not sense the potential urgency of the situation and chose to respond in a way consistent with current training practices such as following the published missed approach. One flight instructor pilot commented that the word "immediate," used in the ATC command, may not be equally interpreted by all pilots, therefore they respond differently. Some may interpret it as "respond as quickly as possible," while others may interpret it as "respond with some urgency, when possible." The long response times of some pilots indicate a need for specialized training for pilots who would be operating at airports with PRM.

6.4 Flight Crew Procedures

6.4.1 Training

Additional training is required for flight crews that are involved in closely spaced simultaneous ILS approach operations. Of primary importance in this training is the difference between a normal missed approach and a monitor controller initiated breakout. It must be clear to the flight crew that the word "immediately" when used by a monitor controller, indicates that the controller is issuing instructions for an emergency maneuver that must be carried out as quickly as possible to maintain separation from another aircraft.

There is another concern for aircraft with autoland capability. When the autoland mode is enabled, the autopilot will fly a straight-out missed approach. If a breakout command is given by the monitor controller, the autoland mode must be explicitly disabled by the flight crew before the turning escape maneuver can be executed.

Additional emphasis should be made for the need to select the standby mode on the transponder whenever the aircraft is not on the active runway, both before departure and after arrival. The extraneous replies caused by aircraft leaving their transponder on while on the ground cause significant surveillance difficulties for existing radars as well as the PRM radars. Checklists should be revised, if necessary, to insure compliance with this requirement.

6.4.2 Airman's Information Manual

Appendix E contains recommended changes to the Airman's Information Manual. These changes incorporate new procedures and terminology relating to simultaneous ILS approaches to parallel runways separated by less than 4,300 ft.

6.5 Obstruction Clearance Surveys

In establishing an instrument approach, the designer must ensure that there are no physical obstructions in the approach path. FAA's Terminal Instrument Procedures (TERPS) relate minimum altitudes in the approach to protective surfaces, usually trapezoidal planes, which, if the approach is to be established, must be above all obstructions.

Since the PRM anticipates that aircraft may be turned away from other aircraft at any point during the approach or missed approach, an obstruction evaluation must be completed for each runway. In cases where obstructions limit the endangered aircraft's ability to maneuver clear of a blunderer, the simultaneous approach could not be established.

6.6 TCAS Interaction with PRM

At the time of flight testing and demonstration in Memphis and Raleigh, the only TCAS available for use was a production prototype TCAS II unit which did not incorporate the most recent software and hardware characteristics of the production designs. Consequently, although the prototype TCAS was operating during portions of the flight testing, no attempt was made to rigorously collect or analyze data on TCAS interaction with PRM. The senior FAA test pilot and several knowledgeable TCAS Program personnel from the FAA Technical Center were on the FAA B727 during the tests and demonstrations, however, and they were subsequently asked to provide qualitative judgments on the interaction of TCAS II with PRM.

One key observation made by the FAA's senior test pilot and TCAS Program personnel was that, during the PRM flight testing and demonstration, in no instance did the TCAS II prototype unit issue a maneuver command (termed a resolution advisory, or RA) which was in conflict with or contradicted the controller's guidance based on the PRM information. It should be noted, however, that TCAS II only provides vertical RAs while a breakout command given by the controller in response to the PRM would, with very high probability, contain turn guidance as well. TCAS III does have both horizontal and vertical RAs and thus would not necessarily have the same interaction characteristics with PRM as TCAS II.

In general, the observers noted that once the aircraft had acquired and stabilized on the localizer and begun descending on the glideslope, the TCAS RA and the controller guidance in response to PRM were most often only separated by a few seconds, usually with the TCAS RA slightly preceding the controller's commands. The observers did note, however, specific instances in which the PRM guidance preceded the TCAS RA, and a few cases for which the anticipated TCAS RA was not issued. The cases for which TCAS did not issue an RA appeared to be those in which the pilot flying the aircraft quickly followed the controller's direction, and the RA was not issued because TCAS alarm threshold conditions were not met.

Some of the more specific comments and recommendations were voiced by the FAA's senior pilot, who presently is also one of the most experienced pilots in TCAS II and TCAS III operation and performance. His observations included two possible modifications to TCAS to assist the flight crew in the conduct of simultaneous ILS approaches. One of these was to provide a selectable one-nautical mile range scale for the TCAS Traffic Advisory display to magnify the display of traffic information presented to the crew and to provide a more readable display of proximate traffic. Another suggestion was to examine the possibility of modifying the TCAS II collision avoidance logic to

provide a special, switch selectable, "Parallel Runway Mode" of operation. This is desirable because the present TCAS II RA thresholds are not optimally matched for closely spaced parallel runways - especially while the aircraft are maneuvering to acquire and stabilize on the localizer and glideslope - and the TCAS RA rates may be higher in these situations than those which have previously been operationally experienced. A short term alternative to any collision avoidance logic modifications would be to switch TCAS into a traffic advisory only mode for parallel ILS approaches.

At present, because of the technical uncertainties and consequential risks involved, it would be premature to consider TCAS alone (either TCAS II or TCAS III) as a substitute for approach monitoring using a PRM system. TCAS operating in the traffic advisory mode is expected to be a useful tool, providing an indication of nearby traffic to the flight crew. It is recommended that, during the course of the TCAS II Transition Program, special emphasis be placed on the functioning of TCAS and the crew response during simultaneous ILS approaches to runways separated by less than 4,300 ft.

6.7 Pilot Acceptance Survey

At Memphis and Raleigh an Aircrew Opinion Survey was completed by the pilots who participated in the blunder simulations using live aircraft. The same survey was given to the pilots who participated in flight simulators at Oklahoma City and Dallas-Ft. Worth during the Raleigh controller response tests. Survey responses were obtained from a total of 195 pilots.

The survey solicited pilot opinion on the acceptability of the PRM system and on pertinent issues applicable to PRM, including: procedures, use of advisories, use of special equipment, and need for additional training The survey was also used to obtain background information on the pilot's amount of flight time: as an airline pilot, in instrument conditions, in type, in simultaneous approaches to parallel runways during IMC.

For simplicity in reporting the results, responses indicating "strongly agree" or "agree" were pooled and reported as agreement. Responses indicating "strongly disagree" or "disagree" were pooled and reported as disagreement. Responses for all pilots were combined, whether they participated in live aircraft testing or flight simulator testing.

Table 6-3 lists the percentage of pilots who agreed, disagreed, or were undecided regarding each survey statement. In addition to the table, the complete text of each survey statement is presented. Pilots made narrative comments regarding several survey statements. Those comments are summarized or reported verbatim following the text of the statement to which they refer.

<u>Statement 2.1</u> Current parallel runway procedures require 1,000 feet of vertical separation at the localizer turn-on for separation, in the event one (or both) aircraft overshoot the localizer course. <u>1,000 feet of vertical separation provides an acceptable safety margin provided aircraft maintain their assigned altitude until glideslope intercept.</u>

<u>Statement 2.2</u> Current radar approach procedures require that ATC assign a heading that will cause an intercept of the localizer course at an angle of 30 deg or less. <u>An intercept of 30 deg or less is adequate to guarantee localizer capture with an overshot of no more than 1.5 deg.</u>

Table 6-3

Summary of Aircrew Opinion Survey Results
from Flight Simulator and Live Aircraft Studies Combined

	Survey Item	Agree (%)	Disagree (%)	Undecided (%)
2.1	1,000-ft vertical separation provides an acceptable safety margin provided aircraft maintain their assigned altitude until glideslope intercept.	96.4	2.1	1.5
2.2	An intercept of 30 deg or less is adequate to guarantee localizer capture with an overshoot of no more than 1.5 deg.	85.6	6.2	8.2
2.3	Due to the importance of not straying into the NTZ, all closely spaced parallel approaches should be conducted with a coupled autopilot.	30.25	59.5	10.25
2.4	The monitor controller should provide an advisory, over the tower frequency, when deviation from the localizer course exceeds half the distance to the NTZ.	79.3	10.9	9.8
2.5	The monitor controller's responsibility should include the localizer turn-on.	73.1	15.5	11.4
2.5.1	The monitor controller's responsibility should extend through the missed approach.	85.0	7.9	7.1
2.6	To emphasize the importance of a quick response, special phraseology should be used for the breakout maneuver.	65.0	30.4	4.6
2.7	TCAS should be required equipment for aircraft conducting closely spaced simultaneous parallel approaches.	30.9	45.4	23.7
2.8	Independent IFR approaches at airports with parallel runways separated by less than 4,300 ft can be safely conducted with PRM.	82.4	3.1	14.5
2.9	Additional pilot training/currency requirements are necessary to qualify pilots for simultaneous independent approaches to parallel runways separated by less than 4,300 ft.	44.6	47.1	8.3
2.10	Deleted.			
2.11	The simulator flight closely approximates those conditions I would expect in actual flight. (Raleigh results only).	81.7	7.3	11.0

<u>Statement 2.3</u> Due to the importance of not straying into the NTZ, all closely spaced parallel approaches should be conducted with a coupled autopilot.

Pilot opinion was divided on this issue. One pilot commented that the system needs to be tested for a coupled approach. No data were collected during the PRM testing to determine if coupled approaches would prevent blunders.

Statement 2.4 With PRM, the monitor controller will be able to detect small deviations from the localizer course. The monitor controller should provide an advisory, over the tower frequency, when deviation from the localizer course exceeds half the distance to the NTZ, even though penetration of the NTZ is not likely.

One pilot, who disagreed with this statement, commented that the monitor should make no advisory comments. He stated that "A radio check, followed by an alert when there is a penetration, should be the only transmissions by the monitor." His concern was that " Anything else would be confusing."

Statement 2.5 Current ATC procedures limit the monitor controller's area of responsibility from the point of the intermediate segment of the approach when 1,000 feet of vertical separation is lost, to a point on the missed approach segment where lateral separation begins. This does not include the turn-on maneuver. The monitor controller's area of responsibility should also include the localizer turn-on.

Statement 2.5.1 The monitor controller's responsibility should extend through the missed approach segment.

Statement 2.6 If an aircraft penetrates the NTZ while another aircraft is conducting a simultaneous parallel approach, the monitor controller will immediately direct the threatened aircraft off its approach course to a heading/altitude that will prevent collision. To emphasize the importance of a quick response from the threatened aircraft, special phraseology should be used for the breakout maneuver.

Several pilots mentioned the need for phraseology that emphasizes the urgency of the instruction. One suggested that the phraseology include "Turn (left/right) immediately for 'collision avoidance' or 'traffic conflict'."

Statement 2.7 TCAS equipment will provide an on-board capability for aircrews to monitor the position of aircraft on a parallel approach. TCAS should be required equipment for aircraft conducting closely spaced simultaneous parallel approaches.

Pilot opinion was divided on this issue. Among the pilots who agreed, several stated that TCAS provided an additional degree of comfort and enhanced their confidence in the PRM system. Among the pilots who disagreed, one pilot mentioned being concerned with "continuous TCAS alerts," if TCAS equipment were required. Another pilot stated that TCAS should not be required even though it would enhance the flight crew's confidence in the PRM system. He stated that "both crew members should be heads-down to monitor deviations of their own aircraft in IMC and they should not be responsible for TCAS monitoring during this phase of the approach." He added that "with PRM up to speed, the monitor controller would have the primary responsibility for separation."

Statement 2.8 Independent IFR approaches at airports with parallel runways separated by less than 4,300 feet can be safely conducted with PRM.

One pilot, who disagreed with the statement, commented that he was "very concerned with pilots blocking out transmissions from controllers."

Statement 2.9 Additional pilot training/currency requirements (e.g., category two and three ILS requirements) are necessary to qualify pilots for simultaneous independent approaches to parallel runways separated by less than 4,300 feet.

In general, pilots either agreed or disagreed on the need for additional training/currency requirements. Very few pilots were undecided. Among the pilots who agreed that training was necessary, one pilot said that this type of approach should be limited to pilots who have specific and annual proficiency training and certification in order to qualify to perform parallel approaches with lower than standard separation. Among the pilots who disagreed that training was necessary, one pilot said that the special phraseology used by the monitor controller would be enough to alert pilots to the serious nature of the situation and the need for an immediate response. One pilot commented that additional training was not necessary, but crew should have sufficient time in aircraft type.

During the review of approach blunders involving flight simulators where the "closest point of approach" was less than 1,000 ft, it was found that lack of proficiency and knowledge of aircraft systems (autoland mode, head-up display) appears to make a significant difference in pilot response time.

Statement 2.11 (This question applies to the Raleigh flight simulator portion of the study only.) The simulator flight closely approximates those conditions I would expect in actual flight.

The pilots who disagreed about flight simulator realism were reacting to the lack of typical communication a pilot would hear on the tower frequency.

General Comments

Comments regarding the system were generally positive in nature. Many pilots reported being impressed with the equipment. Pilots mentioned concerns regarding the following areas:

(a) Human Response Time -- One pilot mentioned his concern with "the human element." In his opinion, the PRM equipment should not pose any problem. His concern was boredom on the part of the monitor controller. Two pilots mentioned having concerns with the response time of both the controller and the pilot.

(b) Need for Advisories and Additional Information -- One pilot commented that ATIS information should alert flight crews that simultaneous approaches with reduced separation are being conducted. Additional information may be indicated on the approach plate.

(c) Frequency Congestion -- One pilot suggested that a minimum of radio reports should be required and suggested deletion of report over the outer marker. He was "very concerned" about pilots blocking out transmissions from controllers.

(d) Need for Additional Testing -- Two pilots mentioned the need for further testing of the system. One pilot commented that intercepts should be flown with various speeds, angles, and wind conditions. Another pilot suggested adding turbulence to the flight simulator testing in order to assess the effect

of increased pilot workload. Several pilots mentioned the need to test the system using a coupled approach.

7. OVERALL SYSTEM PERFORMANCE

Highlights

- **All valid flight simulator and live aircraft blunders were resolved with more than a 500-foot miss distance.**
- **Model results show that a 1- versus 2.4-second update interval provides only a small improvement in the system's ability to resolve worst case blunders at runway separations of 3,400 ft. The 1-second interval resolves 997 out of 1,000 30-deg blunders, the 2.4-second interval resolves 996.**
- **The need to resolve a blunder as severe as 30 degrees is by far the most demanding constraint on the system design.**

This chapter discusses the results achieved by the PRM as a total system in keeping aircraft separated during simultaneous independent parallel approaches. There are three sections: the first discusses the minimum separations achieved during live aircraft demonstrations; the second covers minimum separations from flight simulator studies; and the third discusses results of the collision risk model developed in association with the PRM program.

Limitations are inherent in the use of each of these techniques - live aircraft, flight simulators, and risk modelling - for evaluation of the effectiveness of the PRM system. The most practical, or tangible, of the techniques is clearly the live aircraft demonstration. It involves all of the human and machine components of the closely spaced approach, and it is tempting to think of it as the ultimate test of the system.

However, live aircraft tests have significant limitations. The preparedness necessary to conduct them safely requires that all participants be relatively aware of what will happen. In contrast with a blunder and an associated breakout in IMC during an otherwise routine flight, an event which will never happen to most pilots or monitor controllers, the demonstration puts pilots and controllers in a situation where they know that a blunder is going to be demonstrated. They are, therefore, more or less prepared for it. Another limitation is in experimental control. Interference from other traffic using the airport during the demonstration, inability to position the aircraft so that an unresolved blunder would result in a midair collision, and intervention by the demonstration pilots to ensure that their aircraft maintain safe separations, can complicate data collection, analysis and interpretation.

The modelling technique carries limitations as well. The model is realistic only to the extent that the builders have included all the relevant factors. If there is an interaction which they have not anticipated, the model will fall short of reality. For example, no one thought to model the breakout problem associated with autoland systems mentioned in Section 6.1.2.2. In addition, without the pilot and controller participation, which would not have been present in a purely analytical exercise, the many ancillary problems that must be resolved before PRM implementation might not have been brought to light.

The work reported in this chapter was designed to use a combination of the evaluation techniques mentioned above. Thus the benefits of each technique were used to offset limitations of the others.

7.1 Flight Test Results

A total of 118 live aircraft demonstration blunders were analyzed from Memphis with the back-to-back radar running at a 2.4-second update interval, and from Raleigh with the E-Scan radar running at a 0.5-second update interval. The data were collected during test flights carried out during June 1990 with an FAA aircraft piloted by volunteer air carrier pilots. See Section 6.2.1 for a description of these tests.

Since these tests involved live aircraft, the worst case blunder scenario could not be completely reproduced during the trials. Thus, the aircraft tracks were modified during subsequent data analysis by extending the flight path of the blundering aircraft during the deviation as though it could not recover, and by positioning the aircraft such that they would have collided if the endangered aircraft had not turned. The normalized miss distance, defined by the closest point of approach, was then determined for each trial.

The distributions of miss distances for the 30-deg blunder scenario inside the outer marker (OM) and the 15-deg blunder scenario outside the outer marker are shown in Figure 7-1. All miss distances were greater than 1,000 ft, with a minimum of 1,252 ft inside the OM and 1,390 ft outside the OM.

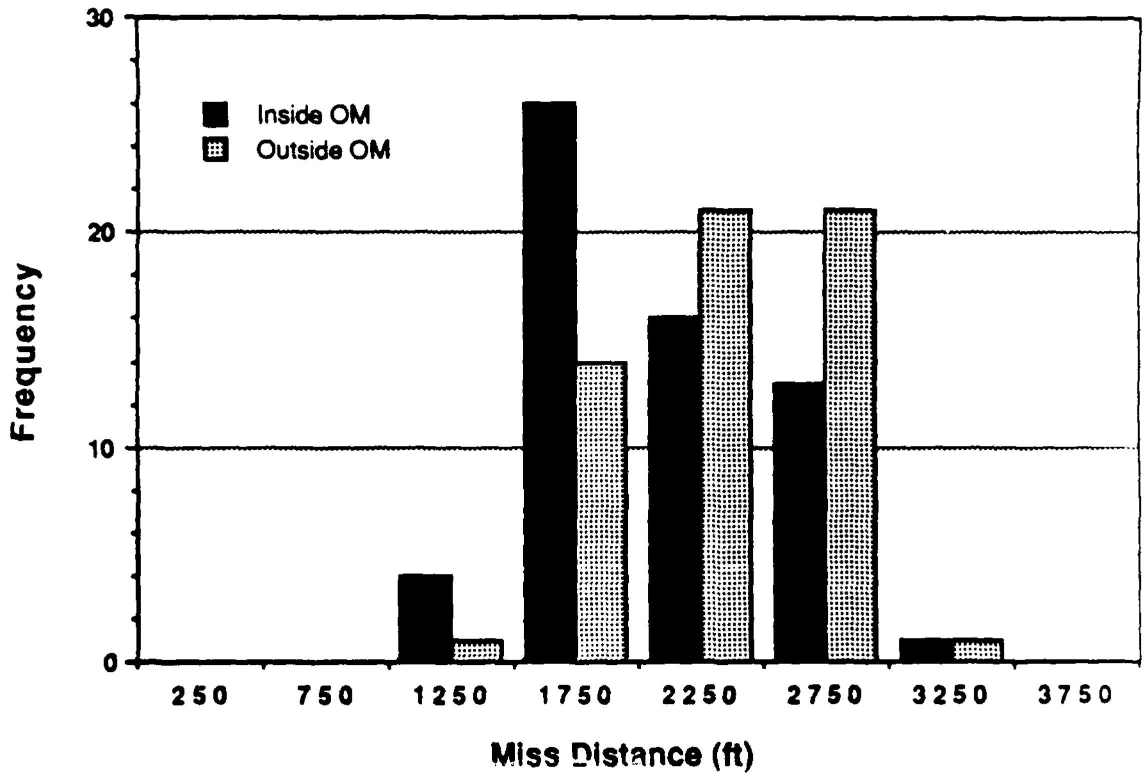

Figure 7-1. Live aircraft miss distances.

7.2 Flight Simulator Results

The flight simulator tracks from the Raleigh study were processed similarly to the live demonstration tracks and normalized miss distances were calculated for each trial. The results are summarized in Table 7-1. All of the 15-deg blunders had a normalized miss distance of at least 1,457 ft. About ten percent of the 30-deg blunders resulted in a normalized miss distance of less than 500 ft. A careful analysis was made for each of these trials to determine why the endangered aircraft response was inadequate. In each case, one or more of the following events occurred:

(a) Difficulty with the equipment. See Section 6.1.2.2 for a detailed description.

(b) Very slow response. The pilot waited an unnecessary length of time before turning and/or turned at less than two degrees per second.

(c) The pilot did not hear the breakout command, or was distracted by events in the cockpit. This included difficulty with the telephone link with the controller and power interruptions.

(d) The controller gave the wrong call sign in the breakout instruction.

Events (a), (b) and (d) can be rectified by training controllers and pilots to be aware of t e situation. Event (c) is an unavoidable side effect of the complexity of the experiment.

Table 7-1

Flight Simulator Miss Distances

Aircraft	Inside Outer Marker		Outside Outer Marker	
	15 deg	30 deg	15 deg	30 deg
B727	2148 ± 329 ft (N = 26)	1024 ± 593 ft (N = 32)	-	1246 ± 562 ft (N = 33)
MD80	-	1197 ± 498 ft (N = 25)	-	1060 ± 534 ft (N = 30)

7.3 Collision Risk Model

Studies have been conducted to quantify the risk associated with simultaneous ILS approaches to parallel runways. A MITRE study [2], assumed a series of events that occur during a blunder resolution. The model used in this study considers the worst case blunder (30 degrees, no communication with the blundering aircraft) and resolves it assuming that the endangered aircraft response is delayed by the total of the maximum radar, controller, and pilot response times. The model output is the minimum allowable runway separation which results in a lateral 200-ft miss distance between aircraft before the endangered aircraft begins to diverge from the worst case blunderer.

This MITRE study led to the assumption on which the PRM program is based: that improved radar update and accuracy could reduce runway separation. Like any model, this one is limited by its assumptions. One of these is that a relatively simple relationship exists between controller response and radar update interval. For example, the model does not

suggest an improvement in response time attributable to an automated prediction of NTZ penetration. Another is that the model produces only a single result of minimum runway spacing. It does not estimate the risk of a collision.

The comprehensive measurement program which has been described in the preceding chapters was constructed to collect better data on the elements of the blunder resolution. With this data, a range of values for each parameter could be determined and incorporated into a new model.

A Monte Carlo collision risk model (CRM) has been developed. For a given set of independent variables (see below), the model simulates 100.000 trial blunders. In each of the them, two aircraft fly down their respective parallel approach courses toward runways whose thresholds are not offset. At a specified point, one of the aircraft rolls into a three-degree per second turn until the prescribed blunder heading is reached. The blundering aircraft continues on the blunder heading at constant altitude. The endangered aircraft continues down the approach path until it turns away after the radar detects the blundering aircraft, the display responds to the radar, the controller responds to the display, and the pilot responds to the controller. The slant (3-D) distance between the aircraft is calculated at one-second intervals from the beginning of the blunder until a minimum has been reached. This closest point of approach defines the miss distance for the trial.

7.3.1 Elements of a Blunder Resolution

For each of the 100,000 blunders, the model draws a value at random for each blunder resolution element from measured data or distributions based on measured data. The elements are:

a. A range of starting positions for the two aircraft before the blunder: the positions vary across the localizer course due to flight technical error, and along the course due to the probability that the blundering aircraft will not always be in precisely the right position to collide with the endangered aircraft. Cross track deviation from the centerlines is a zero mean normal distribution with a range dependent standard deviation derived from the Memphis field data described in Chapter 3. The along track position of the endangered aircraft is uniformly distributed between 1.5 nmi behind and 1.5 nmi ahead of the blundering aircraft. The blundering aircraft flies at 170 knots at 10 nmi and 140 knots at 2 nmi from the runway threshold.

b. A range of times between the start of a blunder and generation of the PRM caution alert. Different distributions of alert times were used for each particular combination of runway separation, radar accuracy, update interval and blunder configuration, as described in Section 2.4. The alert response includes a half-second delay between radar target detection and target display.

c. A set of monitor controller responses to the caution alert chosen from measured data for the selected blunder configuration, update interval and runway separation. The controller response data for the model were collected at Memphis, as described in Chapter 4.

d. A set of delays due to blockage of the communications frequency on which the breakout instruction will be delivered. The length of the

delay is randomly chosen from a distribution based on pilot transmission data collected at Memphis, as described in Chapter 5.

e. A set of aircraft tracks generated by flight simulators whose pilots responded to the monitor controller's breakout instruction. Tracks recorded during the OKC B727 and Federal Express DC10 crew performance studies are inserted into the simulation from the point at which the monitor controller began the breakout instruction, and adjusted to match the endangered aircraft track from the simulation at that point. The track is randomly selected from the set of tracks for the selected blunder range. The distributions of pilot response times to start of turn are shown in Figure 7-2 for scenarios starting 2 nmi from the runway and in Figure 7-3 for scenarios starting 10 nmi from the runway.

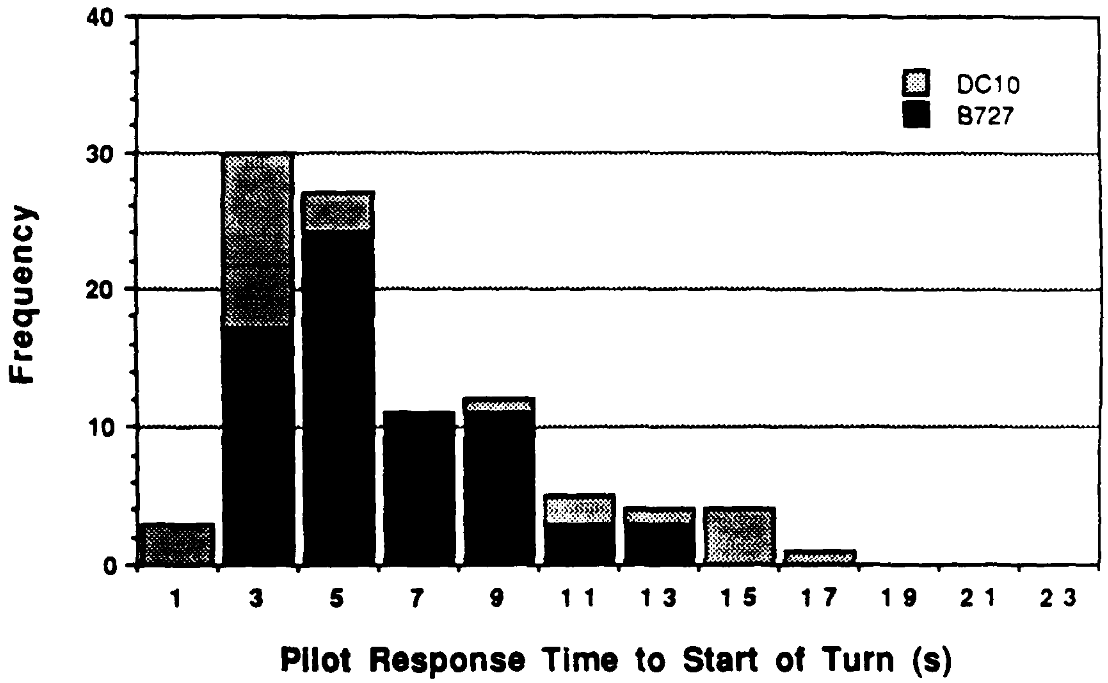

Figure 7-2. Nominal case pilot responses for blunder at 2 nmi.

7.3.2 Independent Variables

The independent variables for each set of 100,000 blunders were:

a. Range of the blundering aircraft at start of blunder, modeled at 2 and 10 nmi. The ranges were selected 1) because the flight technical error is greater at the 10-nmi range, and 2) the pilot response was assumed to be slower at the relatively closer distance.

b. The blunder heading, modeled for 15 and 30 degrees. The 30-degree blunder is the worst case, while the 15-degree blunder was modeled to understand the collision probabilities for less severe cases.

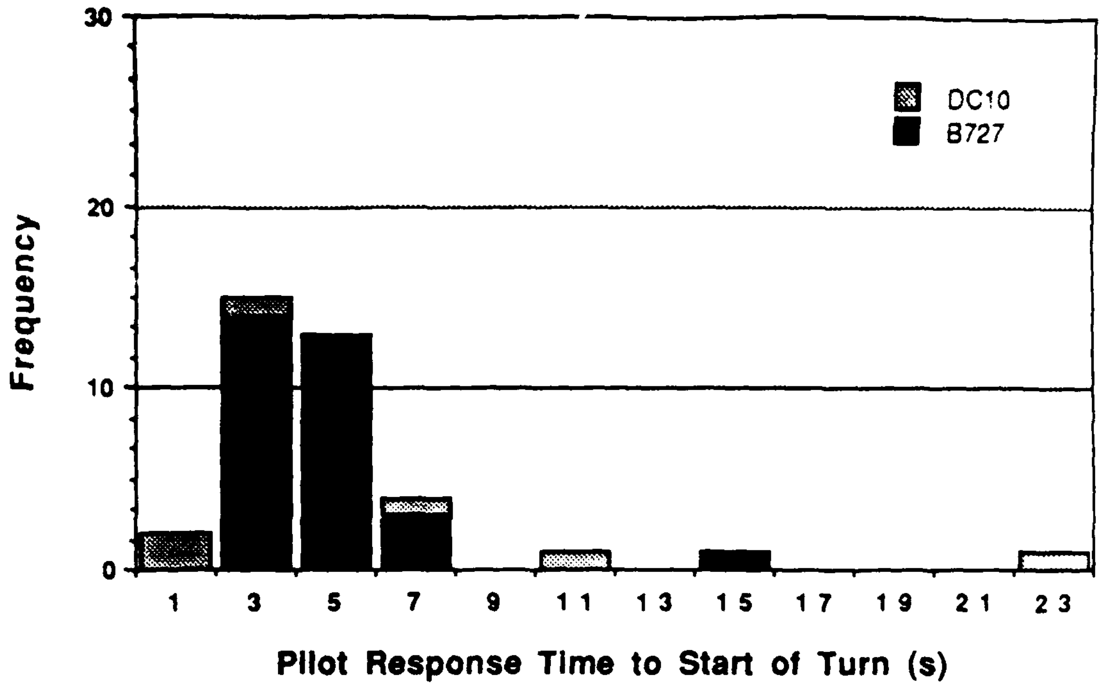

Figure 7-3. Nominal case pilot responses for blunder at 10 nmi.

c. The runway separation, modeled at 3,000, 3,400, and 4,300 ft. The 4,300-ft distance matches the current U.S. national standard. The 3,400-ft separation is the distance between the runways at Memphis, and was the MITRE model's prediction of the lowest separation at which a 2.4-second update would yield satisfactory results. The 3,000-ft separation was selected to explore the risk of a lower spacing.

d. The radar update interval, modeled at 1.0, 2.4 and 4.8 seconds. The 4.8-second interval was chosen because an unmodified Mode S sensor would produce that update interval with improved accuracy. 2.4 seconds is the back-to-back interval, and a 1.0-second interval is available with E-Scan. A 0.5-second interval was not used because this would provide only a half second of additional time compared to the 1.0-second interval. Also, preliminary examination of the Raleigh controller results suggests that the distribution of controller response times is not improved with this radar update interval.

e. The radar accuracy, modeled at 1 and 2 milliradians. Most of the simulations were modeled at 1 milliradian, the accuracy of either the back-to-back or E-Scan radars. The 2-milliradian sensor was modeled to show the effect of the ASR-9 radar, and was modeled only at that radar's 4.8-second update interval.

f. The set of pilot/aircraft responses available to the model for selection in each trial. In most cases, what was termed the "nominal" set does not include the B727 tracks for the three subject pilots who consistently exhibited unusually slow response times (see Section 6.1.1.1). To test the sensitivity of the model to the set of tracks, a

few cases had the nominal set either enhanced by adding the slow tracks or diminished by excluding the DC10 tracks.

7.3.3 Results

The outputs from this simulation are distributions of the miss distances achieved for each of the 100,000 runs in each scenario. Representative cumulative distributions of miss distances are shown in Figure 7-4. This type of representation is designed to determine the probability of having a miss distance less than or equal to a desired value for a given scenario. The discussions below are based on a minimum miss distance requirement of 500 ft. For that distance, the probability for the scenario in Figure 7-4 can be read from the inset in (a) as 0.3 percent, or about 1 in 300, and in (b) as 0.4 percent, or 1 in 25091

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7.3.3.1 Effect of Runway Separation

7.3.3.1.1 3,400 ft

This was the case of most interest, since most of the controller simulations and all of the live aircraft demonstrations were conducted at the nominal 3,400-ft runway separation prevailing at Memphis and Raleigh. Table 7-2 shows the model results for a variety of input parameters: three update rates, two blunder ranges, and two blunder angles.

Table 7-2

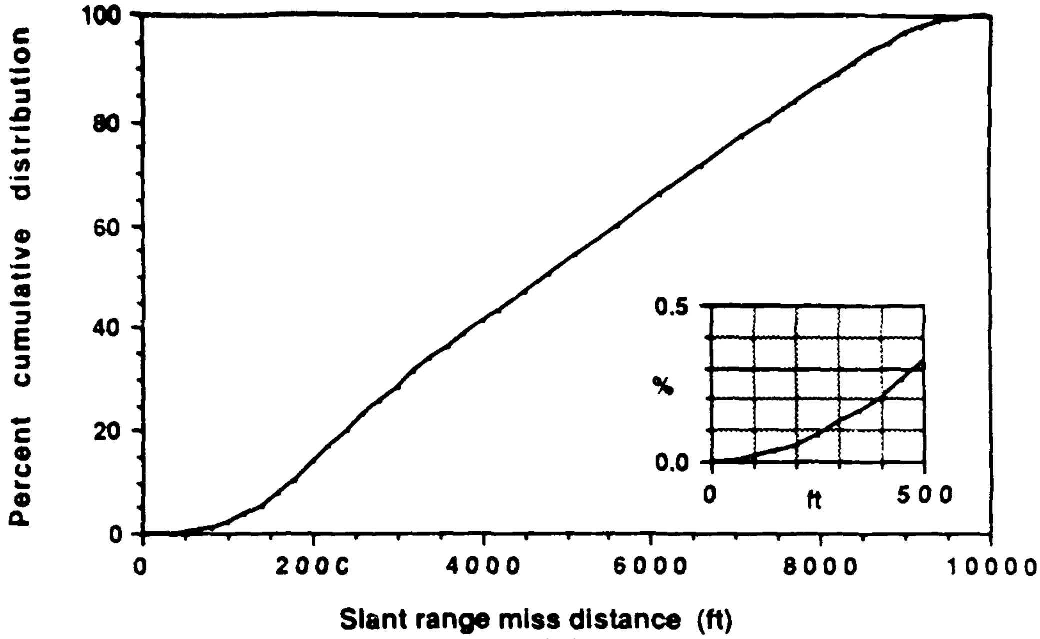
Percent of Trials with Miss Distance Less than 500 ft
Runway Separation: 3,400 ft

15-deg Blunder			**30-deg Blunder**		
Update	2 nmi	10 nmi	Update	2 nmi	10 nmi
1.0	0.000	0.005	1.0	0.207	0.319
2.4	0.000	0.004	2.4	0.394	0.389
4.8	0.000	0.015	4.8	1.027	1.616

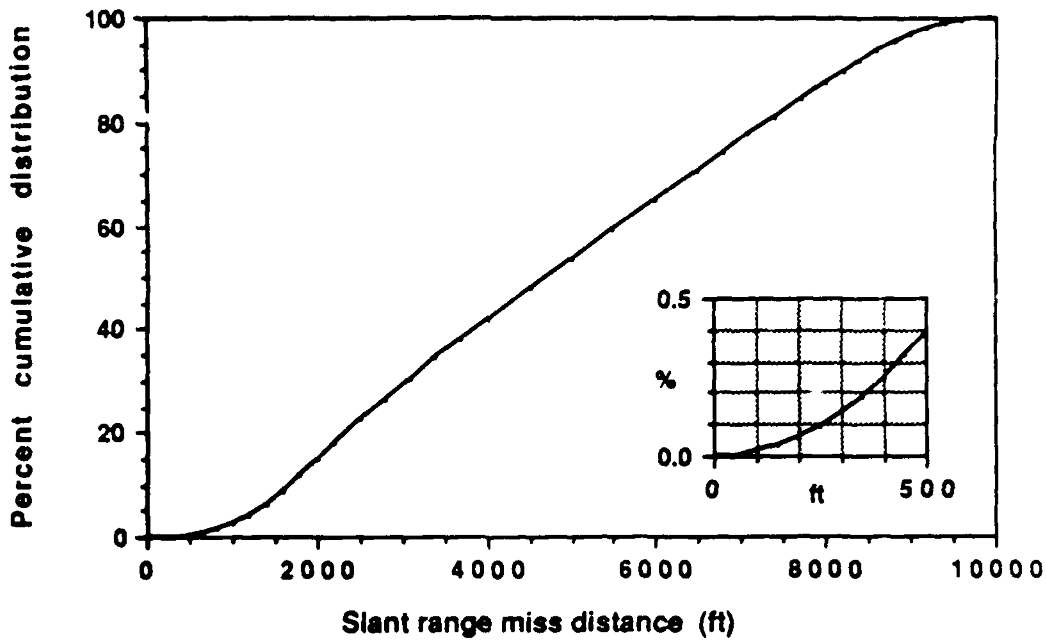
Blunder angle: There were very few miss distances less than 500 ft for the 15-degree scenarios. The worst result was 15 per 100,000 trials (0.015%) for a blunder at 10 nmi and a 4.8-second update interval. The miss distance probabilities are on the order of 100 times lower for the 15-degree blunder compared with 30 degrees. This points out how heavily the system design depends on the 30-degree angle chosen for the worst case blunder.

Blunder range: The probabilities are slightly higher at the 10-nmi distances, probably due to higher airspeed and the increased flight technical error which reduces the initial separation from which the blunder is staged. Any effect of slower pilot response times at 2 nmi was offset by the effects of decreased FTE and airspeed compared to the longer range.

Update interval: Results for the 1.0-s and 2.4-s update intervals were similar for all blunder scenarios, with the 1.0-s update interval performing slightly better. The results were much worse for the 4.8-s update interval, where at least one 30-degree blunder out of 100 could result in a miss distance less than 500 ft.



(a)



(b)

Figure 7-4. Cumulative distribution function for miss distance. Inset is an enlargement for the first 500 ft. Runway separation: 3,400 ft. Blunder configuration: 30-deg at 10 nmi. (a) 1.0-s update interval. (b) 2.4-s update interval.

7.3.3.1.2 3,000 ft

The 3,000-ft case was modeled to gain some understanding of a narrower spacing. The elements of the blunder resolution in the model are valid at 3,000 ft except for the controller response time. It must be assumed that the controller response might differ if the controller were viewing a smaller normal operating zone (500 ft on each side rather than 700 ft for the 3,400-ft separation). Table 7-3 shows the model results for a variety of input parameters: two runway separations, two update rates, and two blunder ranges.

Table 7-3

Effect of Runway Separation on Miss Distance.
Percent of Trials with Miss Distance less than 500 ft*

3,000-ft Runway Separation			3,400-ft Runway Separation		
Update	2 nmi	10 nmi	Update	2 nmi	10 nmi
1.0	0.650	0.498	1.0	0.207	0.319
2.4	0.924	0.688	2.4	0.394	0.389

*30-deg blunder

Runway separation: The blunder resolution ability is diminished with the narrower separation.

Blunder range: Blunders are harder to resolve at 2 than at 10 nmi for the narrower spacing. This is the opposite of the trend at the 3,400-ft separation, and the difference is possibly due to transponder range bias. It may be that range bias is a more important factor at reduced runway separations.

Update interval: The effect of the different update rates is more clearly differentiated than in the 3,400-ft case. This suggests that as the time available to resolve the blunder shrinks along with the spacing, the shorter update interval provides additional time which is more important at the narrower separation.

7.3.3.1.3 4,300 ft

PRM blunder resolution performance was tested at a 4,300-ft runway separation for the "least favorable" condition: a 4.8-s update interval and 30-degree blunders at 10 nmi. Two radar azimuth accuracies were tested: 1-milliradian (Mode S), and 2-milliradian (ASR-9). The same controller response distribution was used for both, and the nominal set of aircraft tracks were used.

The 4,300-ft case was modeled to gain some understanding of today's standard. Unlike the 3,000-ft case, controller response data were available because the 4,300-ft spacing was presented to the controllers at Memphis, although there were not as many replications. The remaining elements of the blunder resolution remain valid. Although the case models today's standard, the equipment assumed is different. Today's controllers have neither Mode S nor ASR-9 azimuth accuracies, and today's lower resolution displays have no predictors.

Radar accuracy: There appears to be no difference in performance with radar accuracy at this spacing and update interval. The percent of trials with miss distances under 500 ft was 0.320% at 1-milliradian accuracy and 0.310% at 2-milliradian accuracy.

Runway Separation: The effect of the runway separation is clear. Table 7-2 shows probabilities of 1.6% at 3,400 ft, compared with 0.32% at 4,300. The utility of the shorter update interval in creating a comparable risk at the lower runway spacing is also evident. The 4,300-ft/4.8-second probability of 0.32% is almost identical to the 3,400-ft/1.0-second result of 0.319%, and only slightly lower than the 3,400-ft/2.4-second result of 0.389%.

7.3.3.2 Effect of Pilot/Aircraft Responses

To understand the sensitivity of the model to the composition of the set of simulator tracks included in the risk model, the nominal set of tracks was first reduced by excluding the DC10 tracks and one B727 track with a response time of 16 seconds. The nominal set was then augmented by adding some B727 tracks generated by pilots who responded much more slowly. Two blunder ranges, two update rates, and 3,400-ft runway separation were used as input parameters to the model along with the modified track sets. Results of model runs using these parameters are shown in Table 7-4.

Table 7-4

Effect of Modifying Pilot/Aircraft Response Tracks
Percent of Trials with Miss Distance Less than 500 ft*

Case	Update	2-nmi Range	10-nmi Range
Nominal	1.0	0.207	0.319
	2.4	0.394	0.389
Reduced	1.0	0.068	0.178
	2.4	0.167	0.296
Augmented	1.0	0.271	0.380
	2.4	0.461	0.549

*30-deg blunder

The risk associated with a blunder is sensitive to changes in the data set. At 10 nmi, the augmented set increased the proportion of pilot response times greater than 15 seconds from five percent to twelve percent, while the reduced set eliminated all response times greater than 7 seconds. These changes in the population resulted in a 20 - 40 percent change in the risk. At 2 nmi, the augmented set increased the proportion of pilot response times greater than 15 seconds from one percent to four percent, increasing the risk 20 - 30 percent, and the reduced set eliminated all response times greater than 13 seconds, decreasing the risk 40 - 65 percent.

7.3.3.3 Sensitivity to Delayed Responses

To test the sensitivity of the model to increased delay in the responses, a constant three seconds was added to all controller response data in the model. Because the controller responses are modeled as a distribution of times, adding a constant at this point is equivalent to adding 3 seconds to all pilot responses, or to the communications delay, or to some combination. It is also roughly equivalent to moving the runways 360 ft closer together.

The 30-degree scenario at 10 nmi was repeated for the 3,400-ft and 3,000-ft runway separations, using the modified controller response distributions. The nominal set

of pilot/aircraft tracks from the previous section was used for the 3,400-ft separation, while the reduced set was used at 3,000 ft. Results of these scenarios are shown in Table 7-5. The probabilities for miss distances less than 500 ft are about triple those for the unmodified response time cases, except for the 1.0 update at 3,400 ft.

Table 7-5

Effect of Longer Controller Response Times on Miss Distance
Percent of Trials with Miss Distance Less than 500 ft*

3,000-ft Separation			3,400-ft Separation		
Update	nominal	+ 3.0 s	Update	nominal	+ 3.0 s
1.0	0.345	1.231	1.0	0.319	0.793
2.4	0.445	1.557	2.4	0.389	1.055

*30-deg blunder at 10 nmi

7.3.3.4 Limitations of CRM Results

For the above analyses, the margin of error in the results due to the models used in the simulation has not yet been estimated. It is believed that a significant source of error is the limited number of tracks available for the endangered aircraft. For the blunder scenarios starting at 10 nmi, there are 31 B727 tracks and 6 DC10 tracks. Thus, the effect of outliers is increased. Another source of error is the model of radar noise. For example, range bias was modeled as a uniform distribution between plus and minus 250 ft, which is the bias for ATCRBS transponders. Using the smaller Mode S transponder value, plus or minus 125 ft, could have improved the target tracker output, and thus improved alert performance, particularly for blunders at 2 nmi. Also, the raw distributions for controller responses were used rather than mathematical models of the distribution curves. Response time values were limited to those actually observed, while the true spectrum of response times would be continuous, with less weight being given to the extreme values. Finally, an actual population mix of large and heavy aircraft was not considered. The true proportion of heavy aircraft is smaller than that used in the simulation. Therefore, because of the above biases, the results are probably conservative.

8. RISK ANALYSIS

Highlights

- **Risk of accidents during closely spaced parallel approaches monitored by PRM will not add significantly to the risk of IMC approaches experienced today.**
- **If closely spaced approaches are implemented at 10 airports, intervals between accidents from a blunder would average about 2,000 years.**

The collision risk model described in Chapter 7 estimates how well the PRM will keep aircraft from colliding (or nearly colliding at a 500-foot miss distance) in a variety of blunder scenarios during closely spaced parallel approaches. The worst scenario tested called for the blundering aircraft to turn 30 degrees towards the adjacent parallel course, and not respond to any monitor controller instructions. This worst case, defined in Section 1.2.2.1, is the most difficult for the PRM, controller, and pilot to resolve. It is more risky than a 15-degree blunder by a factor of 100.

While Chapter 7 determined a per blunder failure rate for worst case blunders under PRM, a more meaningful statistic would be the rate per approach. Then, the closely spaced parallel approach risk could be compared to other accident risks. The problem is that to determine a per approach rate, one must know how often worst case blunders occur. Yet no blunder -- worst case or other -- has ever resulted in an accident, and there is only anecdotal data about blunders without accidents. A sustained 30-degree blunder would be a memorable event for a monitor controller or pilot. But today, with parallel approaches conducted at several busy airports (with runways separated by 4,300 feet or more), few pilots or controllers have ever witnessed or even heard of such a blunder.

One way to evaluate closely spaced parallel approach safety without blunder data is to select an acceptably small "per approach" accident rate, and then compute a rate of blunders that, combined with the PRM's ability to resolve them, attains that level. If that rate is well above anyone's intuitive sense of how often worst case blunders occur, then the system will be well above the desired level of safety.

8.1 Selecting a "Per Approach" Accident Rate

In selecting an "acceptably small" accident rate, one is tempted to demand zero, but nearly any change to a system introduces some risk. A more realistic demand is that risk added by the change be low compared to other risks already in the system.

The most obvious risk against which to compare PRM would be that from widely spaced parallel approaches over the last several years. However, only a few airports are currently running independent parallel approaches and no midair collisions have occurred, so an evaluation of this risk level is not possible. Instead, the risk level associated with the final approach phase of flight for domestic airports is examined. Only air carrier data are considered; although PRM would be used for other classes of aircraft, the air carrier accident rate is lowest and will generate the most stringent criterion for PRM.

Accident data are available from the National Transportation Safety Board (NTSB). Table 8-1 presents NTSB data on fatal accidents by U. S. domestic air carriers during all phases of flight from 1983 to 1988, inclusive [10]. Over the 6 year period, there were two approach accidents, both in IMC. Out of 33.3 million approaches, about 5.0 million approaches were in IMC, for an IMC accident rate of 1 accident per 2.5 million approaches. Only IMC approaches are considered because it is assumed that the PRM would be used only in IMC, or that if it was used in VMC, pilot sighting of the blundering aircraft would be sufficient to avoid the blunder without aid from the PRM.

Table 8-1

Air Traffic Fatal Accident Statistics for 1983 - 1988

Phase of Flight	Reported Fatal Accidents	Fatal Accident Rate (per Approach)
Start and Taxi	1	$2.9998 \cdot 10^{-8}$
Take-off	6	$1.7999 \cdot 10^{-7}$
Climb	0	-
Cruise	3	$8.9995 \cdot 10^{-8}$
Descent	1	$2.9998 \cdot 10^{-8}$
Approach	2	$5.9997 \cdot 10^{-8}$
Landing	1	$2.9998 \cdot 10^{-8}$
TOTAL	14	$4.19979 \cdot 10^{-7}$

Nine causes of accidents during a final approach have been identified, including engine failure, collision with an obstacle, and aircraft deviation from the approved flight path. PRM would add a tenth cause of an accident: an unresolved blunder during PRM operation. Since there have been few recorded fatal accidents, the actual contribution of each of these events to the final approach statistics is unknown. For this analysis, we assume each of the events, including fatal midair accidents during PRM operations, to be equally likely to occur. Each category would then contribute about one tenth of the total accident rate. Using this, the target safety level for the category of midair collisions during PRM operations is 1 fatal accident per 25 million IMC approaches, which is expressed as:

$$\frac{1 \text{ accident}}{25 \text{ million approaches}}$$

8.2 Acceptable Blunder Rate

The next question is the number of 30-degree blunders that would have to occur before the target risk level is exceeded. There are 3 elements to this computation:

1. It is assumed that in only one percent of 30-degree blunders would the pilot be unable to respond to a controller direction to return to course. A prolonged communications failure might prevent the controller from communicating with the pilot, or the sudden onset of a storm cell or loss of control effectiveness due to an engine failure, could render the aircraft temporarily unable to maintain the proper heading. Whatever the possible cause, the assumption says that in 99% of the 30-degree blunders, the pilot would hear and be able to respond to the controller

direction to return to course. This assumption is expressed as one worst case blunder (WCB) for every 100 30-degree blunders (BL), or

$$\frac{1 \text{ WCB}}{100 \text{ BL}}$$

2. Chapter 7 models the worst case blunder to have a rate of one collision for every 250 worst case blunders (repeating the conservative assumption that a miss distance of less than 500 feet is a collision). Since the NTSB reports a collision as two accidents, this result can be expressed as two fatal accidents per 250 WCB's, or

$$\frac{2 \text{ accidents}}{250 \text{ WCB}}$$

3. Another factor is needed to correct the computation for the fact that two approaches will be involved in every PRM blunder possibility. This is expressed as

$$\frac{2 \text{ approaches}}{\text{approach pair}}$$

Combining the three terms with the target level of safety from Section 8.1 yields the following expression and result:

$$\frac{1 \text{ accident}}{25 \text{ mill. appr.}} \times \frac{100 \text{ BL}}{\text{WCB}} \times \frac{250 \text{ WCB}}{2 \text{ accidents}} \times \frac{2 \text{ approaches}}{\text{approach pair}}$$

$$= \frac{1 \text{ BL}}{1{,}000 \text{ approach pairs}}$$

This suggests that if the PRM can resolve 249 of 250 30-degree uncorrected blunders, then one 30-degree blunder can be tolerated for every 1,000 pairs of closely spaced parallel approaches.

This number can now be related back to the anecdotal level of reasonableness suggested in Section 8.1. If the target accident rate of 1 midair accident for 25 million approached during PRM operations is to be achieved, then the number of 30-deg blunders, determined from documented and anecdotal evidence, must be less than 1 per 1,000 pairs of simultaneous ILS approaches.

Statistics from recent 12 month periods at Atlanta Hartsfield and Chicago O'Hare airports are shown in Table 8-2. Each of these airports runs simultaneous independent parallel approaches much of the time. The Chicago data, for example, suggest that 10,000 pairs of independent parallel approaches were conducted in IMC during 1989. If the goal of one accident per 25 million IMC approaches is to be achieved, Chicago should be experiencing no more than about 10 30-degree blunders per year during IMC. At Atlanta, the expectation translates to about 14 blunders per year.

Anecdotal evidence suggests that the actual rate is less than this for both airports, with near certainty that the rate does not exceed even one per year. This suggests that the actual fatal accident rate will be much smaller than the target rate of 1 per 25 million approaches. Assuming a ceiling of one deviation, or blunder, per year at these two

airports, the expected midair accident rate during PRM operations will be, at most, one fatal accident per 250 million approaches.

Table 8-2

Approach data for Chicago and Atlanta

Category	Chicago	Atlanta
Total IFR Approaches	405,455	374,175
IMC Approaches	67,136	142,186*
Simultaneous IMC Approaches	20,141	27,015
Allowable 30° Blunders per Year	10	14

*the higher ratio of IMC to total approaches at Atlanta results from counting approaches as IMC if the aircraft were in clouds when vertical separation was lost, even though the field could be operated under visual flight rules

8.3 <u>Summary</u>

The analysis in this chapter requires several assumptions, and the target criteria must be viewed as estimates of reality. To counter this uncertainty and ensure the safety of PRM operation, all assumptions are conservative and therefore lower the target risk level. This in turn lowers the maximum rate of 30-degree blunders that can be tolerated if PRM is to provide an acceptable level of safety. The available evidence indicates that the actual rate of 30-degree blunders is in fact less than this conservative estimate of the maximum tolerable rate. Therefore, the actual fatal accident rate, once PRM is implemented, will be smaller than the target rate.

Given the expected actual accident rate of 1 per 250 million approaches, a measure of safety can be obtained by estimating how often one could expect an accident during PRM operation. Based on recent airport operations data and projected PRM usage, assuming installation at 10 airports, PRM can be expected to account for about 125,000 IMC approaches per year in the 1990's. This suggests that on average there will be no more than one midair collision during PRM operations per 2,000 years.

9. FOLLOW ON RESEARCH AND DEVELOPMENT

The development and field evaluations of the PRM equipment suggest additional applications for this technology. These topics have been deferred so as not to delay the implementation of the PRM system. Monitoring of approaches to converging and intersecting runways is also deferred. This section provides a brief discussion of these topics and suggests that they be the subject of future developmental activities.

9.1 Parallel Approach Monitoring for Separations Less than 3,400 ft

The development performed to reduce the minimum runway separation for simultaneous ILS approaches from 4,300 ft to 3,400 ft should be continued to achieve further reductions, the goal being 2,500 ft. Specific areas of additional development are listed below.

9.1.1 Caution Alert Design

The basic design of the caution alert should be optimized for runway separations between 2,500 ft and 3,400 ft. This requires consideration of the prediction vector length, unnecessary breakout rate, controller response, FTE and radar parameters. Human performance tests should be carried out, taking advantage of the experience gained to date to determine the performance and acceptability of the PRM for separations less than 3,400 ft. Additional tests should be performed to gain more insight into unnecessary breakout rates. These tests can be performed at the FAA Technical Center using PRM display and simulation equipment from the Memphis demonstration site.

9.1.2 Radar Update Interval

The effect of reduced update interval should be examined for runway separations between 2,500 ft and 3,400 ft.

9.1.3 Blunder Documentation

It is recommended that procedures be developed to obtain information on all significant deviations that occur during parallel dependent and independent ILS approaches. This information will significantly assist the process of risk assessment and the extension of the PRM to smaller runway separations.

9.2 Parallel Departure Monitoring

Current air traffic procedures require that if aircraft depart simultaneously from parallel runways in IMC, each aircraft must be immediately turned at least 15 degrees away from the other departing aircraft within 1 nmi after passing the end of the runway. This cannot be done at some airports due to noise constraints. A staggered departure sequence must be used, reducing the departure rate by about 50%. If the PRM system is used to monitor departures, it may be possible to delay the need for the 15-degree turn until a higher altitude, and eliminate the need for the staggered departure. It is recommended that this concept be studied and a demonstration of departure monitoring by an appropriate PRM system be conducted.

9.3 ASR-9 Monitoring

The ASR-9 primary radar is now being deployed and provides an azimuth accuracy of about 2.0 milliradians at a 4.8-second update interval. It appears that the current parallel

approach monitoring at airports having larger (greater than 4,300 ft) runway separations could be improved if the ASR-9 digital output prior to the (video) reconstitutor were provided to the display system proposed for use by the back-to-back and E-Scan monitors. Further, if new primary radar tracking techniques now being developed for the ASR-9 are used, automatic blunder alerting could be provided.

9.4 Converging Approach Monitoring

The PRM program was originally designated as the Parallel and Converging Approach Monitor program, based on the supposition that new sensor and display technology would improve the arrival rates to converging runways. Further analysis of converging approaches indicated that current capacity constraints are not significantly related to radar precision or update interval. The following sections discuss this further and provide recommendations for additional research and development.

9.4.1 Dependent Converging Approach Monitoring

Dependent converging approaches are currently used when the involved runways cross. This requires the two streams of aircraft to be staggered so as to provide a 2-nmi separation when the first aircraft is over its missed approach point. An imaging technique has been developed that provides a visual spacing aid for the final approach controller. Special symbols (ghosts) are displayed, based on a geometric calculation that images aircraft from one approach onto the other converging approach. The technique is currently being implemented at St. Louis and may be implemented at other locations.

An enhancement of the imaging technique is expected to be provided by the Terminal Air Traffic Control Automation (TATCA) Program, where the symbols will be designed to optimize the runway acceptance rate, accounting for other factors such as wind, wake turbulence, and aircraft performance. It appears at this time that it is unnecessary to provide higher update radars to support the current ghosting technique and the future TATCA enhancement.

9.4.2 Independent Converging Approach Monitoring

Independent converging approaches are currently used when approach paths intersect. The concern in this procedure is with maintaining safe separation should aircraft conduct simultaneous missed approach procedures. To assure this, protection zones are provided, based primarily on data obtained by flight tests and full motion flight simulators that determined the lateral distributions of aircraft after the missed approach point has been passed. The contribution to the width of these buffer zones by surveillance errors is small.

Two issues should be addressed to determine potential improvements to independent converging approaches with the PRM. First, the data used to establish the protection zones were for aircraft that flew normal ILS approaches and missed approach flight paths. The flight crews therefore had localizer course guidance only for a short distance past the missed approach point. In addition, the localizer is narrow and difficult to follow due to the small range to the ILS antenna at the far end of the runways. Thus the lateral deviations were largely based on maintaining the same heading. It is possible that the deviations experienced during this data collection activity overstate the deviations that will be experienced during independent converging missed approaches because the missed approach point will be several nautical miles farther from the localizer antenna. The additional distance will provide longer and less sensitive localizer guidance, which should reduce the later deviations. This suggests that the missed approach point could be moved closer to the runway and lower in altitude.

The second issue regards the possibility of narrowing the protection zone widths by use of monitoring procedures similar to those used during simultaneous ILS approaches. A PRM sensor could be configured to provide caution alerts should aircraft on either approach begin to deviate towards the other approach path. If practical and effective, this would reduce the lateral deviations, permit protection zone narrowing, and would result in a lowering of the weather minimums. A research program to explore both of these may be useful.

9.5 New Techniques

As discussed in Chapter 1, the fast track nature of this program prevented consideration of a number of new techniques, or even departures from existing techniques. Further research might consider:

a. The reduction in width or changes in the shape of the NTZ.

b. The use of MLS for curved or angled approaches to increase separation during most of the approach.

c. The potential contribution of state-of-the-art autopilots to insuring separation.

d. Use of collision avoidance logic in the controller displays to replace strict reliance on the NTZ to guide controllers in blunder resolution.

e. The use of TCAS as a method for situational awareness, or even as a means for transferring responsibility for separation on closely spaced parallel approaches to the cockpit.

APPENDIX A

Memphis Scenarios

The following scenarios involve aircraft conducting independent parallel approaches, and were presented at 1.0-, 2.4-, and 4.8-second update intervals:

	Scenario	Angle	Range (nmi)	Flight Path Condition
1.	Single Blunder	30 deg	2-4	Calm
2.	Single Blunder	30 deg	2-4	Calm
3.	Single Blunder	30 deg	8-12	Calm
4.	Single Blunder	30 deg	8-12	Crosswinds
5.	Single Blunder	30 deg	2-4	Crosswinds
6.	Single Blunder	30 deg	8-12	Crosswinds
7.	Distraction, followed by a Blunder	15 deg	8-12	Calm
8.	Distraction, followed by a Blunder	30 deg	8-12	Calm
9.	Fast/Slow Blunder	15 deg	2-4	Calm
10.	Fast/Slow Blunder	15 deg	8-12	Calm
11.	Simultaneous Missed Approach Blunder	15 deg	0.5	Calm

These scenarios were presented at 1.0- and 2.4-second sensor update intervals (not at the 4.8-second update interval):

	Scenario	Angle	Range (nmi)	Flight Path Condition
1.	Single Blunder	15 deg	2-4	Calm
2.	Single Blunder	15 deg	2-4	Crosswinds

APPENDIX B

Raleigh Scenarios

The following scenarios involve aircraft conducting independent parallel approaches, and were presented at 0.5-, 1.0-, 2.4-, and 4.8-second update intervals:

	Scenario	Angle	Range	Comments
1A.	Single Blunder	30 deg	at the outer marker	The pilot of the blundering aircraft will ignore the controller's breakout instruction.
2A.	Single Blunder	15 deg	at the outer marker	same as above
3A.	Single Blunder	30 deg	outside outer marker	same as above
4A.	Fast/Slow Blunder	30 deg	at the outer marker	same as above
6A.	Drift deviation Blunder	see comment	after passing the initial fix	Aircraft drifts from course at a sufficient angle to generate a caution alert.
9A.	Transponder Failure (Coast Status)	not applicable	at various points along the approach course	One aircraft experiences a simulated transponder failure.
10A.	Single Blunder / Return to Course	15 deg	at the outer marker	The pilot of the blundering aircraft will respond to the controller's instruction and return to course.
12A.	Simultaneous Missed Approach Deviations	15 deg	50 ft above the touchdown zone elevation	
13A.	Simultaneous Missed Approach Blunder	30 deg	Missed approach point	
14.	Blunder on short final	30 deg	3 nmi inside the final approach fix	The pilot of the blundering aircraft will ignore the controller's breakout instruction.

APPENDIX C

Memphis and Raleigh Facility Orders

Memphis Facility Order

SUBJ: Simultaneous ILS Approaches

1. PURPOSE. This Notice assigns responsibilities for testing simultaneous ILS approaches at the Memphis International Airport.

2. DISTRIBUTION. This Notice is distributed to the facility files and is of interest to all operational personnel.

3. RESPONSIBILITIES.

a. TRACON Supervisor shall:

(1) Ensure ARF/ARM and CIA are staffed during live test phases, ARF/ARM shall control test aircraft only.

(2) Inform the Tower Cab Supervisor prior to and upon completion of live testing.

b. Arrival Coordinator (CIA) shall:

(1) Coordinate sequences for test aircraft with the appropriate arrival control and, to the extent practical, plan sequences so as to provide expeditious handling for these aircraft.

c. Arrival Radar East/West (ARE/ARW) shall:

(1) Ensure that when test aircraft are established on the final approach courses, succeeding arrivals are a minimum of 5 NM in trail.

d. Arrival Final West (ARF) shall:

(1) Establish all aircraft on final, clear aircraft for the approach and accomplish frequency change to the tower prior to the step down fix.

(2) Ensure test aircraft have a minimum 5 NM in-trail spacing with preceding arrivals.

(3) Control test aircraft on frequency 126.7.

(4) After transferring communications of the test aircraft to the tower, continue monitoring frequency 126.7 and advise the CC of breakouts initiated by FMW. Note: Transfer of control from FMW to ARF shall be when FMW transmits "standby for approach control."

e. Arrival Final East (ARM) shall:

(1) Establish all aircraft on final, clear aircraft for the approach and accomplish frequency change to the tower prior to the step down fix.

(2) Ensure that aircraft have a minimum of 5 NM in-trail spacing with preceding arrivals.

(3) Control test aircraft on frequency 120.07.

(4) After transferring communications of test aircraft to the tower, continue monitoring frequency 120.07 and advise the CC of breakouts initiated by FMW.
Note: Transfer of control from FME to ARM shall be when FME transmits "standby for approach control."

f. Final Monitor West (FMW) shall:

(1) Control test aircraft on frequency 126.7.

(2) Be responsible for separation from the step down fix through the missed approach procedure.

(3) Transfer control to ARF by transmitting to the test aircraft "standby for approach control."

g. Final Monitor East (FME) shall:

(1) Control test aircraft on frequency 120.07.

(2) Be responsible for separation from the step down fix through the missed approach procedure.

(3) Transfer control to ARM by transmitting to the test aircraft "standby for approach control."

h. FMW/FME shall:

(1) Assign runway breakout headings and altitudes outside the outer markers as follows:

Runway	Heading	Altitude
18L	090	3000
18R	270	2000
36L	270	2000
36R	090	2000

i. Tower supervisor shall:

(1) Ensure CC, LC1, and LC2 are staffed during live test phases.

j. Cab Coordinator shall:

(1) Relay breakout information to LC1 and LC2 as appropriate.

(2) Accomplish handoffs to ARF/M as appropriate for test aircraft which execute missed approaches.

k. Local Control (LC) shall:

(1) Ensure that the potential final monitor breakout areas are protected from other traffic operations in the airport traffic area.

(2) Assign the published test missed approach procedure to aircraft that execute missed approaches.

(3) Retain control of missed approach aircraft until advised by the CC.

SUBJ: SIMULTANEOUS ILS APPROACHES

1. PURPOSE. This order establishes procedures for conducting simultaneous ILS approaches at the Raleigh-Durham International Airport.

2. BACKGROUND. Since the runways are separated by only 3,500 feet, simultaneous ILS approaches are not authorized. However, with the development of E-Scan Secondary Surveillance Radar, it is feasible to reduce the separation minima to allow these approaches at Raleigh-Durham. These procedures are designed to be used during the testing of the E-Scan radar and ultimately used when the test is complete and the equipment certified for unrestricted use.

3. EFFECTIVE.

4. POLICY. Dual Local Control positions are mandatory.

5. ACTION. Responsibilities and procedures.

a. TRACON Supervisor shall:

(1) Ensure that two monitors are positioned before beginning simultaneous ILS approaches. All simultaneous ILS approaches shall be monitored.

(2) Inform monitors of the first and last two aircraft that are to be monitored.

(3) Coordinate with the Tower Supervisor/CIC when simultaneous ILS approaches will commence and when they will terminate.

(4) Cancel simultaneous ILS approaches when the ARTS is inoperative.

b. Final Controller (EFR, WFR).

(1) Traffic vectored to either the 5R/23L or 5L/23R localizer for a simultaneous ILS approach shall be turned on so as to ensure the aircraft are established on the localizer outside the SCHOO, PRSTN, JONDI, and BRAAD fixes, except in the following cases:

(a) Visual separation is applied.

(b) Parallel ILS approaches (two-nautical mile stagger) are utilized.

(c) 1,000 feet vertical or a minimum of three nautical miles radar separation between aircraft during turn-on to parallel localizer courses is provided.

(d) Final controllers providing separation in accordance with (a), (b), or (c) above are responsible for that separation until:

1. The aircraft is established on the localizer, and

2. The aircraft is on the appropriate local control frequency.
NOTE: Simultaneous ILS approaches are not authorized when an aircraft does not have an operable transponder.

(2) Traffic vectored to the Runway 5R/23L localizer shall not be turned on below 4,000 MSL unless coordination has been effected with the WFR controller.

(3) Traffic vectored to Runway 5L/23R localizer shall be at or below 3,000 MSL at least three nautical miles from the East Final Approach course unless coordinated with EFR.

NOTE: Noise abatement procedures for jets, i.e., 3,000 MSL until 10 DME, still apply.

(4) Any aircraft turned on to the final approach inside the initial approach fix shall be coordinated with the monitor controllers in advance.

(5) Simultaneous ILS/Visual Approaches - FR controllers shall conduct their operation so that the following criteria are met when conducting simultaneous ILS/Visual approaches:

(a) ILS East Final/VA West Final.

1. East Final Radar.

a. Uses ILS approaches.

b. Normally turns on outside the initial approach fix to maintain 4,000 MSL until the initial approach fix.

2. West Final Radar.

a. Uses visual approaches.

b. Establishes aircraft on a heading to intercept the final approach at an angle not greater than 20 degrees.

c. Normally issues a clearance limit of 3,000 MSL or below.

d. Ensures separation is maintained from ILS traffic until VA aircraft has received and acknowledged for the visual approach clearance.

(b) ILS West Final/VA East Final.

1. East Final Radar.

a. Uses visual approaches.

b. Establishes aircraft on a heading to intercept the final approach course at an angle not greater than 20 degrees.

c. Normally issues a clearance limit of 4,000 MSL or above.

d. Ensures separation is maintained from ILS traffic until VA aircraft has received and acknowledged for the visual approach clearance.

2. West Final Radar.

a. Uses ILS approaches.

b. Turns on outside the outer marker with aircraft at or below 3,000 MSL at least three nautical miles from the East Final Radar Approach course.

(6) E/WFR shall ensure separation between aircraft on downwind and aircraft on final approach in the event of pull-outs. Downwind traffic shall remain at 4,000 or above until abeam the IAF.

(7) Final controllers shall advise the final monitors of any nontransponder aircraft executing the approach.

(8) Final controllers shall advise the final monitors of any aircraft not conducting an ILS approach.

(9) When conducting simultaneous ILS approaches or simultaneous ILS/VA's, aircraft executing the ILS approach shall be instructed to contact the appropriate local control in sufficient time to allow an initial call by the IAF, but shall not be changed to the Tower frequency prior to 15 nautical miles or prior to being established on the localizer. Aircraft on the visual approach should be changed to the Tower frequency prior to five nautical miles from the runway.

c. *Monitor* (EFM and WFM).

(1) When simultaneous ILS approaches are in progress, the monitor controllers are responsible for separation from the IAF through the missed approach procedure. When the aircraft are turned on using the procedures in 5.b.(l) (a), (b), or (c), the monitor controller begins separation responsibility when the aircraft are changed to the Tower frequency. Coordination must be accomplished with the Tower when issuing missed approach instructions to provide dual missed approach separation.

Simultaneous missed approaches, inside 1NM final shall be monitored until course divergence (a minimum of 15 degrees) is observed. Monitors shall coordinate with Local Control when issuing pull out instructions inside 1NM final. After conflicts are resolved, the aircraft can be transferred to the appropriate departure/arrival controller.

(2) Monitors shall write the identification of arriving aircraft under their control and retain this documentation until transfer of control is accomplished. Monitors shall use a writing tablet to keep track of the arrival sequence and to ensure aircraft have been switched to Tower frequency prior to crossing the IAF. Include the following information as a minimum:

(a) Arrival sequence.

(b) Use a check mark (√) after the aircraft ID to indicate the aircraft has checked on Tower frequency.

(c) Draw a line through aircraft ID when the aircraft has landed.

(3) Ensure that any monitor initiated pull-outs are coordinated with the appropriate FR controller.

(4) Monitoring shall be performed on an off scope scanning 5 NM beyond departure end of the runway in use and 5 NM outside the IAF.

(5) Monitors shall obtain a TMTR/RCVR check prior to beginning monitoring. The local controller shall key his/her mike during the radio check to ensure override capability. All frequencies at the Local Control position will be overridden.

(6) Monitors shall advise the appropriate Local Control of the first and last aircraft to be monitored.

(7) Monitors shall not begin or terminate monitoring until advised to do so by the TRACON supervisor.

(8) Prior to a monitor assuming separation responsibility of an aircraft, the following conditions must be met:

(a) The aircraft is established on the localizer.

(b) The aircraft is over or inside the IAF.

(c) The aircraft is on the appropriate local control frequency.

(9) When an aircraft is established on the localizer and has not contacted the Tower by the IAF, it is the monitor's responsibility to initiate action to have the aircraft changed to the appropriate Local Control frequency.

(10) In the event of a transponder failure for an aircraft established on the final approach course inside the IAF, the following procedures shall apply.

(a) If the aircraft are encountering IMC conditions and are less than two staggered nautical miles apart on adjacent localizer courses, both aircraft shall be pulled out and coordination effected with the appropriate controller.

(b) If a failed transponder occurs and adjacent localizer traffic is not a factor, then coordination should be effected and parallel ILS approach separation (two-nautical mile staggered) should be applied by the final controller.

(c) If a failed transponder occurs at a point where the Tower can provide visual separation, then coordination should be effected to transfer control and responsibility to the appropriate Local Control.

(11) Pull-outs shall be issued the following headings and altitudes.

R/W	POSITION	ALTITUDE	HEADING
23R	IAF-R/W	3000	320
23L	IAF-R/W	3000	140

5R	IAF-R/W	3000	140
5L	IAF-R/W	3000	320

(12) The following phraseology will be used when issuing pull-out instructions:

(identification) TURN RIGHT IMMEDIATELY HEADING (heading)

(climb/descend/maintain) (altitude), (traffic information)

d. Local Controllers.

(1) Prior to commencing simultaneous ILS approaches, the Tower BRITE will be set on a range setting which encompasses the IAF's.

(2) Local Control may, after coordinating with the appropriate monitor, assume visual separation responsibility between aircraft at any point inside the outer-marker (FAF) when weather permits.

(3) Local Control is responsible for advising the monitor when weather conditions deteriorate to a point where visual separation is not a usable procedure.

(4) Local Control shall not adjust the speeds of aircraft on the final approach.

APPENDIX D

Proposed Controller Handbook Changes

5-127
SIMULTANEOUS ILS/MLS APPROACHES - HIGH UPDATE RADAR

TERMINAL

a.
When parallel runways are separated from 3,400 feet to 4,300 feet authorize simultaneous ILS, MLS, or ILS and MLS approaches to parallel runways if precision runway monitors are utilized with a radar update rate of 2.4 seconds,or less and:

(1) Straight-in landings will be made.

(2) ILS, MLS, radar, and appropriate frequencies are operating normally.

b.
Prior to aircraft departing an outer fix, inform aircraft that simultaneous ILS/MLS approaches are in use. This information may be provided through the ATIS.

c.
On the initial vector inform the aircraft of the ILS/MLS runway number.

Phraseology:

I-L-S RUNWAY (runway number) (left/right).

M-L-S RUNWAY (runway number) (left/right).

d.
Clear the aircraft to descend to the appropriate glideslope/glidepath intercept altitude soon enough to provide a period of level flight to dissipate excess speed. Provide at least 1 nautical mile of straight flight prior the final approach course intercept.

5-127d Note. -- Not applicable to curved and segmented MLS approaches.

e.
Vector the aircraft to intercept the final approach course at an angle not greater than 30 degrees.

f.
Provide a minimum of 1,000 feet vertical or a minimum of 3 nautical miles radar separation between aircraft during turn-on to parallel final approach. Provide the minimum applicable radar separation between aircraft on the same final approach course.

5-127f Note. -- Aircraft established on a final approach course are separated from aircraft established on an adjacent parallel final approach course provided neither aircraft penetrates the depicted NTZ.

g.
When assigning the final heading to intercept the final approach course, issue the following to the aircraft:

(1) Position from a fix on the localizer course or the MLS azimuth course.

(2) An altitude to maintain until established on the localizer course or the MLS azimuth course.

5-127g(2) Reference. -- Arrival Instructions, 5-123.

(3) Clearance for the appropriate ILS/MLS runway number approach.

Phraseology:

POSITION (number) MILES FROM (fix). TURN (left/right) HEADING (degrees). MAINTAIN (altitude) UNTIL ESTABLISHED ON THE LOCALIZER. CLEARED FOR I-L-S RUNWAY (number) (left/right) APPROACH.

POSITION (number) MILES FROM (fix). TURN (left/right) HEADING (degrees). MAINTAIN (altitude) UNTIL ESTABLISHED ON THE FINAL APPROACH COURSE. CLEARED FOR M-L-S RUNWAY (number)(left/right) APPROACH.

h.
Monitor all approaches regardless of weather. Monitor local control frequency to receive any aircraft transmission. Issue control instructions as necessary to ensure aircraft do not enter the "no transgression zone" (NTZ).

5-127h Note 1. -- Separate monitor controllers, each with transmit/receive and override capability on the local control frequency, shall ensure aircraft do not penetrate the depicted NTZ. Duties of the monitor controllers are limited to ensuring that aircraft do not penetrate the NTZ and they may not be delegated the responsibility for providing the minimum applicable longitudinal separation between aircraft on the same final approach course.

5-127h Note 2. -- An NTZ at least 2,000 feet wide is established equidistant between runway centerlines extended and is depicted on the monitor display. The primary responsibility for navigation on the final approach course rests with the pilot. Therefore, control instructions and information are issued only to ensure that aircraft do not penetrate the NTZ. Pilots are not expected to acknowledge those transmissions unless specifically requested to do so.

5-127h Note 3. -- For the purposes of ensuring an aircraft does not penetrate the NTZ, the "aircraft " is considered the center of the digitized target for that aircraft.

(1) When aircraft are observed to overshoot the turn-on or to continue on a track which will penetrate the NTZ, instruct the aircraft to immediately return to the correct final approach course.

Phraseology:

YOU HAVE CROSSED THE FINAL APPROACH COURSE. TURN (left/right) IMMEDIATELY AND RETURN TO LOCALIZER/AZIMUTH COURSE,

TURN (left/right) AND RETURN TO LOCALIZER/AZIMUTH COURSE.

(2) When an aircraft is observed penetrating the NTZ, instruct aircraft on the adjacent final approach course to alter course to avoid the deviating aircraft.

Phraseology:

TURN (left/right) IMMEDIATELY HEADING (degrees), CLIMB AND MAINTAIN (altitude).

(3) Terminate radar monitoring when one of the following occurs:

(a) Visual separation is applied.

(b) The aircraft reports the approach lights or runway in sight.

(c) The aircraft has landed or in the event of a missed approach is 1/2 nautical mile from the runway departure end.

(4) Do not inform the aircraft when radar monitoring is terminated.

(5) Do not apply the provisions of paragraph 5-180 for simultaneous ILS, MLS, or ILS and MLS approaches.

i

When simultaneous ILS, MLS, or ILS and MLS approaches are being conducted to parallel runways, consideration should be given to known factors that may in any way affect the safety of the instrument approach phase of flight, such as surface wind direction and velocity, wind shear alerts/reports, severe weather activity, etc. Closely monitor weather activity that could impact the final approach course. Weather conditions in the vicinity of the final approach course may dictate a change of approach in use.

APPENDIX E

Proposed Changes to Airman's Information Manual

Section 4. ARRIVAL PROCEDURES

Paragraph 375. Simultaneous ILS/MLS Approaches

a. System: An approach system permitting simultaneous ILS/MLS, or ILS and MLS approaches to airports having parallel runways separated by at least 4,300 feet between centerlines, or, to airports having parallel runways separated by less than 4,300 feet but at least 3,400 feet between centerlines where there is a Precision Runway Monitor radar installed and certified for unrestricted use. Integral parts of a total system are ILS, or MLS, radar, communications, ATC procedures, and appropriate airborne equipment. The Approach Procedure Chart permitting simultaneous approaches will contain the note "simultaneous approach authorized Rwys (__L) and (__R)" identifying the appropriate runways as the case may be. When advised that simultaneous ILS approaches are in progress, pilots shall advise approach control immediately of malfunctioning or inoperative receivers or if simultaneous approach is not desired.

b. Radar Monitor Service: This service is provided for each ILS/MLS to insure prescribed lateral separation during approaches. At those airports where runways are closer than 4,300 feet and a Precision Runway Monitor radar is required, there will be dual monitor positions for all such approaches. Approaches will be monitored by two controllers through the missed approach to at least one-half nautical mile past the departure end of the runway being approached. Pilots will be assigned frequencies to receive advisories and instructions. Aircraft deviating from either final approach course to the point where the no transgression zone (an area at least 2,000 feet wide) may be penetrated will be instructed to take corrective action.

EXAMPLE:

"Turn (left/right) immediately, heading (degrees), climb and maintain (altitude)."

If an aircraft fails to respond to such instruction, the aircraft on the adjacent final approach course may be instructed to alter course.

REFERENCES

1. "Parallel ILS/MLS Approaches," *Air Traffic Controllers Handbook*, Federal Aviation Administration, Par 5-125,126.

2. A.L. Haines and W.J. Swedish, "Requirements for Independent and Dependent Parallel Instrument Approaches at Reduced Runway Spacing," MITRE Corporation (May 1981), FAA EM-81-8.

3. ACP-5-12K, "PRM Beacon Radar System Performance Document," August 8, 1988.

4. Proof of Performance Report, MSI/Bendix. To be published.

5. W. I. Wells, "Verification of DABS Sensor Surveillance Performance (ATCRBS Mode) at Typical ASR Sites Throughout CONUS," MIT Lincoln Laboratory ATC-79, 20 December, 1977.

6. "Precision Runway Monitor Quarterly Technical Letter," MIT Lincoln Laboratory 42QTL-PRM-90-02, 29 May 1990.

7. J. Thomas and D. Timoteo, "Chicago O'Hare Simultaneous ILS Approach Data Collection and Analysis," DOT/FAA/CT-TN90/11.

8. M. Owen, "A Study of Instrument Landing System Localizer Deviations: Autopilot Versus Handflown," MIT Lincoln Laboratory ATC Project Memo 42PM-PRM-0004, 13 February 1990.

9. M. Orgun and S. Flannigan, The Boeing Company 747-757-767 Autopilot Flight Director Systems Group, (letters and personal communication, 1990).

10. J. Yates, Ph.D., Consultant to FAA AVN-540, (letters and personal communications, 1990).

GLOSSARY

ACF	Area Control Facility
AGL	Above Ground Level
ALPA	Air Line Pilots Association
ARTS	Automated Radar Terminal System
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATIS	Automatic Terminal Information System
BL	Blunder
BTB	Back-To-Back
CALT	Caution Alert Lead Time
CRM	Collision Risk Model
CSPA	Closely Spaced Parallel Approaches
DEDS	Data Entry and Display Subsystem
DH	Decision Height
DTS	Desk Top Simulator
EPR	Engine Pressure Ratio
E-Scan	Electronically Scanned
FAA	Federal Aviation Administration
FTE	Flight Technical Error
IFR	Instrument Flight Rules
ICAO	International Civil Aviation Organization
ID	Identification
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
MAP	Missed Approach Point
MLS	Microwave Landing System
MSAW	Minimum Safe Altitude Warning
MSL	Mean Sea Level
NAS	National Airspace System
NBAA	National Business Aircraft Association
NOZ	Normal Operating Zone
NTSB	National Transportation Safety Board
NTZ	No Transgression Zone
OKC	Oklahoma City
OM	Outer Marker
PRM	Precision Runway Monitor
PVD	Plan View Display
RA	Resolution Advisory
RMS	Root Mean Square
TATCA	Terminal Air Traffic Control Automation
TRACON	Terminal Radar Approach Control
TCAS	Traffic Alert and Collision Avoidance System
TERPS	Terminal Instrument Procedures
TMF	Transportable Measurement Facility
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
WCB	Worst Case Blunder
WSI	Weather System Incorporated